

Report No. CG-D-03-97

## Smoke Leakage Through Class A Boundaries

David T. Sheppard  
Karl W. Aittaniemi

Underwriters Laboratories  
333 Pfingsten Road  
Northbrook, IL 60062-2096

Worcester Polytechnic Institute  
100 Institute Road  
Worcester, MA 01609

DISTRIBUTION STATEMENT A  
Approved for public release  
Distribution Unlimited



Final Report  
January 1997

This document is available to the U.S. public through the  
National Technical Information Service, Springfield, Virginia 22161

Prepared for:

U.S. Department of Transportation  
United States Coast Guard  
Marine Safety and Environmental Protection, (G-M)  
Washington, DC 20593-0001

and

U.S. Coast Guard  
Research and Development Center  
1082 Shennecossett Road  
Groton, CT 06340-6096

DTIG QUALITY INSPECTED 2

19970224 138

# NOTICE

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof.

The United States Government does not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

The contents of this report reflect the views of the Coast Guard Research & Development Center. This report does not constitute a standard, specification, or regulation.



  
G.I. Gunther  
Commanding Officer  
United States Coast Guard  
Research & Development Center  
1082 Shennecossett Road  
Groton, CT 06340-6096

Technical Report Documentation Page

|  |   |  |   |
|--|---|--|---|
| 1. Report No.<br><b>CG-D-03-97</b>   | 2. Government Accession No.                                     | 3. Recipient's Catalog No.   |   |
| 4. Title and Subtitle<br><br><b>Smoke Leakage Through Class A Boundaries</b>   |   | 5. Report Date<br><b>January 1997</b>  | 6. Performing Organization Code   |
| 7. Author(s)<br><br><b>David T. Sheppard and Karl W. Aittaniemi</b>  |   | 8. Performing Organization Report No.<br><br><b>UA214/94NK28659</b>  |   |
| 9. Performing Organization Name and Address<br><br>Worcester Polytechnic Institute<br>100 Institute Road<br>Worcester, MA 01609  |   | 10. Work Unit No. (TRAIS)<br><b>R&amp;DC 36/95</b>   | 11. Contract or Grant No.<br><br><b>DTCCG39-93-F-E00676</b>                             |
| 12. Sponsoring Agency Name and Address<br><br>U.S. Coast Guard<br>Research and Development Center<br>1082 Shennecossett Road<br>Groton, CT 06340-6096  |   | 13. Type of Report and Period Covered<br><br><b>Final Report</b><br><b>October 1993 - June 1994</b>  | 14. Sponsoring Agency Code<br><br><b>Commandant (G-MSE)</b><br><b>USCG Headquarters</b> |
| 15. Supplementary Notes<br>The Coast Guard technical contact is Mr. Louis Nash (860-441-2763) of the U.S. Coast Guard Research and Development Center. The Headquarters Project Officer is Mr. Klaus Wahle of the Office of Marine Safety, Security, and Environmental Protection.   |   |  |   |
| 16. Abstract<br><br>This report describes the testing and analysis of smoke leakage through fire doors, fire dampers, and fire stops while verifying their fire endurance meets International Maritime Organization (IMO) requirements for Class A. The report includes descriptions of the test procedures followed, the assemblies tested, and the results obtained.<br><br>The purpose of this project was to develop data that the United States Coast Guard could use when addressing a regulatory discontinuity in the fire test requirements for Class A divisions. Regulation 3.3 of Chapter II/2 of the 1974 International Convention for The Safety of Life At Sea (SOLAS) requires that Class A divisions be "constructed as to be capable of preventing the passage of smoke and flame to the end of the one-hour fire test". The standard fire test evaluates the passage of flame by use of a cotton wool pad. It has no provision for determining the passage of smoke. An objective of this project was also to develop a smoke leakage test protocol and to identify acceptance criteria to complement the standard IMO one hour fire tests for Class A divisions.<br><br>Tests were conducted on seven (7) fire doors, two (2) fire dampers, and two (2) fire stops. All samples tested were found to pass the one hour fire test without permitting the passage of flame past the door. Two A-15 rated fire doors were tested, and both marginally failed the thermal transmission requirement for the A-15 rating. All other samples were found to meet the acceptance criteria when applicable to the sample rating.<br><br>All samples permitted more leakage after the fire test than was allowed before the fire test. The report provides comparisons of leakage rates before and after the fire tests. |   |  |   |
| 17. Key Words<br><br>Fire Tests, Fire Doors, Fire Stops, Fire Dampers, Marine Bulkhead, Class A, Smoke, IMO Res. A517(13), ISO 5925/1  |   | 18. Distribution Statement<br><br>This document is available to the U.S. public through the National Technical Information Service, Springfield, VA 22161. |   |
| 19. Security Classif. (of this report)<br><br><b>UNCLASSIFIED</b>  | 20. SECURITY CLASSIF. (of this page)<br><br><b>UNCLASSIFIED</b> | 21. No. of Pages   | 22. Price   |

# METRIC CONVERSION FACTORS

## Approximate Conversions to Metric Measures

| Symbol          | When You Know          | Multiply By                | To Find                    | Symbol          | When You Know                     | Multiply By       | To Find                | Symbol          |
|-----------------|------------------------|----------------------------|----------------------------|-----------------|-----------------------------------|-------------------|------------------------|-----------------|
|                 |                        |                            | <u>LENGTH</u>              |                 |                                   |                   | <u>LENGTH</u>          |                 |
| in              | inches                 | * 2.5                      | centimeters                | mm              | millimeters                       | 0.04              | inches                 | in              |
| ft              | feet                   | 30                         | centimeters                | cm              | centimeters                       | 0.4               | in                     | in              |
| yd              | yards                  | 0.9                        | meters                     | m               | meters                            | 3.3               | feet                   | ft              |
| mi              | miles                  | 1.6                        | kilometers                 | km              | kilometers                        | 1.1               | yards                  | yd              |
|                 |                        |                            | <u>AREA</u>                |                 | <u>AREA</u>                       | 0.16              | square inches          | in <sup>2</sup> |
| in <sup>2</sup> | square inches          | 6.5                        | square centimeters         | cm <sup>2</sup> | square centimeters                | 0.16              | square yards           | yd <sup>2</sup> |
| ft <sup>2</sup> | square feet            | 0.09                       | square meters              | m <sup>2</sup>  | square meters                     | 1.2               | square miles           | mi <sup>2</sup> |
| yd <sup>2</sup> | square yards           | 0.8                        | square kilometers          | km <sup>2</sup> | square kilometers                 | 0.4               | acres                  | acres           |
| mi <sup>2</sup> | square miles           | 2.6                        | hectares                   | ha              | hectares (10,000 m <sup>2</sup> ) | 2.5               |                        |                 |
|                 |                        |                            | <u>MASS (WEIGHT)</u>       |                 | <u>MASS (WEIGHT)</u>              |                   |                        |                 |
| oz              | ounces                 | 28                         | grams                      | g               | grams                             | 0.035             | ounces                 | oz              |
| lb              | pounds                 | 0.45                       | kilograms                  | kg              | kilograms                         | 2.2               | pounds                 | lb              |
|                 | short tons             | 0.9                        | tonnes                     | t               | tonnes (1000 kg)                  | 1.1               | short tons             |                 |
|                 |                        |                            | <u>VOLUME</u>              |                 | <u>VOLUME</u>                     |                   |                        |                 |
| tsp             | teaspoons              | 5                          | milliliters                | ml              | milliliters                       | 0.03              | fluid ounces           | fl oz           |
| tbsp            | tablespoons            | 15                         | milliliters                | ml              | liters                            | 0.125             | cups                   | c               |
| fl oz           | fluid ounces           | 30                         | milliliters                | ml              | liters                            | 2.1               | pints                  | pt              |
| c               | cups                   | 0.24                       | liters                     | l               | liters                            | 1.06              | quarts                 | qt              |
| pt              | pints                  | 0.47                       | liters                     | l               | liters                            | 0.26              | gallons                | gal             |
| qt              | quarts                 | 0.95                       | liters                     | l               | cubic meters                      | 35                | cubic feet             | ft <sup>3</sup> |
| gal             | gallons                | 3.8                        | liters                     | l               | cubic meters                      | 1.3               | cubic yards            | yd <sup>3</sup> |
| ft <sup>3</sup> | cubic feet             | 0.03                       | cubic meters               | m <sup>3</sup>  |                                   |                   |                        |                 |
| yd <sup>3</sup> | cubic yards            | 0.76                       | cubic meters               | m <sup>3</sup>  |                                   |                   |                        |                 |
|                 |                        |                            | <u>TEMPERATURE (EXACT)</u> |                 | <u>TEMPERATURE (EXACT)</u>        |                   |                        |                 |
| °F              | Fahrenheit temperature | 5/9 (after subtracting 32) | Celsius temperature        | °C              | Celsius temperature               | 9/5 (then add 32) | Fahrenheit temperature | °F              |
|                 |                        |                            |                            |                 |                                   |                   |                        |                 |

\* 1 in = 2.54 (exactly).

## Table of Contents

|  | <u>Page</u> |
|--|-------------|
| List of Figures.....                                       | vi          |
| List of Tables .....                                       | viii        |
| Abbreviations.....   | ix          |
| 1. INTRODUCTION .....                                      | 1           |
| 1.1 Background.....  | 1           |
| 1.2 Method .....   | 1           |
| 1.3 Samples.....   | 2           |
| 2. APPARATUS .....   | 3           |
| 2.1 Air Leakage Chamber.....                               | 3           |
| 2.2 Furnace .....  | 4           |
| 2.3 Test Frame.....  | 4           |
| 2.4 Bulkheads.....   | 4           |
| 2.5 Instrumentation .....                                  | 5           |
| 2.5.1 Data Acquisition.....                                | 5           |
| 2.5.2 Fire Test - Furnace Temperatures .....               | 5           |
| 2.5.3 Fire Test - Furnace Pressure .....                   | 5           |
| 2.5.4 Fire Test - Sample Temperatures .....                | 5           |
| 2.5.5 Fire Test - Sample Deflection .....                  | 6           |
| 2.5.6 Leakage Test - Volumetric Flow Rate .....            | 6           |
| 2.5.7 Leakage Test - Static Pressure Measurements .....    | 7           |
| 3. SAMPLES .....   | 7           |
| 3.1 Sample Construction .....                              | 7           |
| 3.1.1 Dampers.....   | 7           |
| 3.1.2 Fire Stops.....                                      | 8           |
| 3.1.3 Doors.....   | 8           |
| 3.2 Sample Installation .....                              | 9           |
| 3.2.1 Dampers.....   | 9           |
| 3.2.2 Fire Stops.....                                      | 9           |
| 3.2.3 Fire Doors.....                                      | 9           |
| 4. TEST PROCEDURE .....                                    | 9           |
| 4.1 Pre-Fire Test Air Leakage .....                        | 9           |
| 4.2 Fire Test.....   | 10          |
| 4.3 Post Fire Test Air Leakage .....                       | 11          |
| 5. TEST RESULTS AND DISCUSSION .....                       | 11          |
| 5.1 Fire Tests .....                                       | 11          |
| 5.1.1 Furnace Performance.....                             | 12          |
| 5.1.2 Bulkheads .....                                      | 12          |
| 5.1.3 Fire Dampers (Samples 1 and 2) .....                 | 12          |
| 5.1.4 Fire Stops (Samples 3 and 4) .....                   | 12          |
| 5.1.5 A-0 Rated Fire Doors (Samples 5, 6, and 7) .....     | 13          |
| 5.1.6 A-15 Rated Fire Doors (Samples 8 and 9) .....        | 13          |
| 5.1.7 UL Listed 1-Hour Fire Doors (Samples 10 and 11)..... | 13          |

## Table of Contents (continued)

|  | <u>Page</u> |
|--|-------------|
| 5.1.8 Summary.....   | 14          |
| 5.2 Leakage Tests .....                                      | 16          |
| 6. TEST METHOD CRITIQUE .....                                | 19          |
| 6.1 Fire Test.....   | 19          |
| 6.2 Leakage Test.....  | 20          |
| REFERENCES .....   | 21          |
| APPENDIX A: Construction Details.....                        | A-1         |
| APPENDIX B: Calibration Information.....                     | B-1         |
| APPENDIX C: Fire Test - Furnace Results .....                | C-1         |
| APPENDIX D: Fire Test - Unexposed Surface Temperatures ..... | D-1         |
| APPENDIX E: Fire Test - Observations and Deflections.....    | E-1         |
| APPENDIX F: Leakage Test Data.....                           | F-1         |

## List of Figures

|   | <u>Page</u> |
|---|-------------|
| Figure 1. Fire Damper Leakage Rates .....                     | 17          |
| Figure 2. Fire Stop Leakage Rates .....                       | 17          |
| Figure 3. A-0 Fire Door Leakage Rates.....                    | 18          |
| Figure 4. A-15 Fire Doors Leakage Rates .....                 | 18          |
| Figure 5. UL Listed 1-Hour Fire Door Leakage Rates.....       | 19          |
| Figure A-1. Air Leakage Chamber .....                         | A-1         |
| Figure A-2. Air Leakage Chamber Ductwork.....                 | A-1         |
| Figure A-3. Test Wall Assembly.....                           | A-2         |
| Figure A-4. Test Wall Assembly.....                           | A-3         |
| Figure A-5. Bulkhead A.....                                   | A-4         |
| Figure A-6. Bulkheads B through D.....                        | A-5         |
| Figure A-7. Bulkhead E .....                                  | A-6         |
| Figure A-8. Furnace Thermocouple Locations .....              | A-7         |
| Figure A-9. Damper Construction (Sample 1) .....              | A-8         |
| Figure A-10. Damper Construction (Sample 1) .....             | A-9         |
| Figure A-11. Damper Thermocouple Locations (Sample 1).....    | A-10        |
| Figure A-12. Damper Schematic(Sample 2) .....                 | A-10        |
| Figure A-13. Damper Thermocouple Locations (Sample 2).....    | A-11        |
| Figure A-14. Fire Stop Thermocouple Locations (Sample 3)..... | A-11        |
| Figure A-15. Fire Stop Thermocouple Locations (Sample 4)..... | A-12        |
| Figure A-16. Door Construction: Sample 5.....                 | A-13        |
| Figure A-17. Door Construction: Samples 7, 8, and 10 .....    | A-14        |

## List of Figures (continued)

|   | <u>Page</u> |
|---|-------------|
| Figure A-18. Door Construction : Samples 6, 9 and 11 .....                            | A-15        |
| Figure A-19. Door Construction : Samples 6, 9 and 11 .....                            | A-16        |
| Figure B-1. Laminar Flow Element Calibration Sheet.....                               | B-2         |
| Figure B-2. Laminar Flow Element Calibration Sheet.....                               | B-3         |
| Figure C-1. Time-Temperature Curve for Bulkhead A .....                               | C-1         |
| Figure C-2. Time-Temperature Curve for Bulkhead B .....                               | C-1         |
| Figure C-3. Time-Temperature Curve for Bulkhead C .....                               | C-2         |
| Figure C-4. Time-Temperature Curve for Bulkhead D .....                               | C-2         |
| Figure C-5. Time-Temperature Curve for Bulkhead E.....                                | C-3         |
| Figure C-6. Furnace Pressures for Bulkhead A.....                                     | C-3         |
| Figure C-7. Furnace Pressures for Bulkhead B.....                                     | C-4         |
| Figure C-8. Furnace Pressures for Bulkhead C.....                                     | C-4         |
| Figure C-9. Furnace Pressures for Bulkhead D.....                                     | C-5         |
| Figure C-10. Furnace Pressures for Bulkhead E.....                                    | C-5         |
| Figure D-1. Unexposed Surface Temperature: Bulkhead A .....                           | D-1         |
| Figure D-2. Unexposed Surface Temperature: Bulkhead B.....                            | D-1         |
| Figure D-3. Unexposed Surface Temperature: Bulkhead C.....                            | D-2         |
| Figure D-4. Unexposed Surface Temperature: Bulkhead D .....                           | D-2         |
| Figure D-5. Unexposed Surface Temperature: Bulkhead E.....                            | D-3         |
| Figure D-6. Unexposed Surface Temperature: Fire Damper (Sample 1).....                | D-3         |
| Figure D-7. Unexposed Surface Temperature: Fire Damper (Sample 2).....                | D-4         |
| Figure D-8. Unexposed Surface Temperature: Fire Stop (Sample 3).....                  | D-4         |
| Figure D-9. Unexposed Surface Temperature: Fire Stop (Sample 4).....                  | D-5         |
| Figure D-10. Unexposed Surface Temperature: A-0 Fire Door (Sample 5).....             | D-5         |
| Figure D-11. Unexposed Surface Temperature: A-0 Fire Door (Sample 6).....             | D-6         |
| Figure D-12. Unexposed Surface Temperature: A-0 Fire Door (Sample 7).....             | D-6         |
| Figure D-13. Unexposed Surface Temperature: A-15 Fire Door (Sample 8).....            | D-7         |
| Figure D-14. Unexposed Surface Temperature: A-15 Fire Door (Sample 9).....            | D-7         |
| Figure D-15. Unexposed Surface Temperature: UL Listed 1-Hour Fire Door (Sample 10)... | D-8         |
| Figure D-16. Unexposed Surface Temperature: UL Listed 1-Hour Fire Door (Sample 11)... | D-8         |

## List of Tables

|   | <u>Page</u> |
|---|-------------|
| Table 1. Sample Description.....                                  | 3           |
| Table 2. Laminar Flow Element Specification.....                  | 6           |
| Table 3. Leakage Test Static Pressure Levels .....                | 10          |
| Table 4. Test Schedule .....                                      | 11          |
| Table 5. Summary of Bulkhead Results .....                        | 14          |
| Table 6. Summary of Sample Results.....                           | 15          |
| Table B-1 Laminar Flow Element Specification.....                 | B-1         |
| Table F-1. Environment During Leakage Tests .....                 | F-1         |
| Table F-2. Pre Fire Test - Uncorrected Leakage Test Results.....  | F-1         |
| Table F-3. Post Fire Test - Uncorrected Leakage Test Results..... | F-2         |
| Table F-4. Pre Fire Test - Corrected Leakage Test Results .....   | F-3         |
| Table F-5. Post Fire Test - Corrected Leakage Test Results.....   | F-4         |

## **Abbreviations**

|        |  |
|--------|--|
| A-0    | Class A bulkhead not rated for thermal transmission    |
| A-15   | Class A bulkhead thermally rated for 15 minutes        |
| A-60   | Class A bulkhead thermally rated for 60 minutes        |
| ft     | Feet   |
| hr     | Hours  |
| IMO    | International Maritime Organization                    |
| in.    | Inches   |
| kcmil  | Electrical cable conductor diameter designation [1]    |
| kg     | Kilograms  |
| lb     | Pounds force   |
| mm     | Millimeters  |
| m      | Meters   |
| min    | Minutes  |
| NA     | Not Applicable   |
| OR     | Over range of the instrument                           |
| Pa     | Pascals  |
| sec    | Seconds  |
| SOLAS  | International Convention For The Safety of Life At Sea |
| Type K | Chromel-Alumel Thermocouples                           |
| UL     | Underwriters Laboratories Inc.                         |
| USCG   | United States Coast Guard                              |
| ,      | Feet   |
| "      | Inches   |

## **1. INTRODUCTION**

### **1.1 Background**

The purpose of this project was to develop data that the United States Coast Guard (USCG) can use when addressing a regulatory discontinuity in the fire test requirements for Class A divisions. Regulation 3.3 of Chapter II/2 of the 1974 International Convention For The Safety of Life At Sea (SOLAS) requires that Class A divisions be "constructed as to be capable of preventing the passage of smoke and flame to the end of the one-hour fire test". The standard fire test [2] evaluates the passage of flame by use of a cotton wool pad. It has no provision for determining the passage of smoke.

An objective of this project is to develop a smoke leakage test protocol and to identify acceptance criteria to complement the standard International Maritime Organization (IMO) one-hour fire tests for Class A divisions.

This report describes the testing and analysis of smoke leakage through doors, fire dampers, and fire stops while verifying their fire endurance meets IMO requirements for Class A divisions. The report includes descriptions of the test procedures followed, the assemblies tested, and the results obtained. The results presented apply only to the materials actually involved in these tests.

When this effort started, the IMO SubCommittee on Fire Protection completed drafting a revised test standard for fire resistant divisions. This draft was contained in Annex 2 of FP 37/22/Add.1 [3]. On 4 November 1993, the IMO General Assembly adopted IMO Resolution A.754(18), Recommendation on Fire Resistance Tests For "A", "B", and "F" Class Divisions.

### **1.2 Method**

The test program described in this report consisted of conducting tests on doors, fire dampers, and fire stops. Smoke leakage through the assemblies was evaluated before and after a fire test. The effect of the fire test on leakage rates was evaluated.

The smoke leakage tests were conducted in accordance with "Fire Tests-Evaluation of performance of smoke control door assemblies - Part 1: Ambient temperature test (ISO 5925/1 1981(E))"[4]. The fire endurance tests were conducted in accordance with "Revised Recommendation on Fire Test Procedures for "A", "B", and "F" Class Divisions (Annex 2 of FP37/22/Add.1)"[5].

A movable test frame was constructed to contain five bulkhead assemblies. Each bulkhead assembly was designed to accept single swinging fire doors or fire dampers and fire stop systems. Each sample in the bulkhead was tested for air leakage, fire tested for a duration of one hour, allowed to cool, then tested for air leakage a second time.

### 1.3 Samples

Descriptions of the samples tested are provided in Table 1. A variety of items were used during the test to determine the variability in resisting passage of smoke. Tests were conducted on seven (7) fire doors, two (2) dampers, and two (2) fire stops. Each specimen tested was of a different design and whenever possible, samples within a class were procured from different manufacturers. A mixture of USCG and Underwriters Laboratories (UL) listed doors were used as the USCG doors were not tested in a furnace for approval. USCG doors are approved based on construction only. The test would provide information as to how well these doors would compare to the UL listed doors. Construction details of the samples are provided in Section 3.

In accordance with the fire test method, the samples were mounted in steel bulkheads for testing. When possible, multiple samples were mounted in each bulkhead. Table 1 provides a list of the bulkhead location of each sample.

**Table 1. Sample Description**

| Sample No. | Sample Description             | Bulkhead | Mounting Location on Bulkhead |
|------------|--------------------------------|----------|-------------------------------|
| 1          | Fire Damper (Class A)          | A        | Top north                     |
| 2          | Fire Damper (UL Listed 1 hour) | A        | Top south                     |
| 3          | Fire Stop (Cable Transit)      | A        | Bottom north                  |
| 4          | Fire Stop (Pipe Penetration)   | A        | Bottom south                  |
| 5          | Fire Door (A-0 Rated)          | E        | South                         |
| 6          | Fire Door (A-0 Rated)          | D        | South                         |
| 7          | Fire Door (A-0 Rated)          | D        | North                         |
| 8          | Fire Door (A-15 Rated)         | B        | South                         |
| 9          | Fire Door (A-15 Rated)         | C        | South                         |
| 10         | Fire Door (UL Listed 1 hour)   | B        | North                         |
| 11         | Fire Door (UL Listed 1 hour)   | C        | North                         |

The following discussion presents the apparatus, instrumentation, samples, procedures and results obtained.

## **2. APPARATUS**

The test apparatus consisted of a large scale vertical furnace, an air leakage chamber, a moveable test frame, and steel bulkheads mounted in the test frame. The test samples were mounted in the steel bulkheads, which in turn were mounted in the movable test frame. The movable test frame was positioned on the furnace for fire tests and in front of the air leakage chamber for the leakage tests.

### **2.1 Air Leakage Chamber**

The chamber was designed to be mounted on the masonry test frame completely covering the steel bulkhead in order to create an air-tight seal. The air leakage chamber consisted of an open-faced welded steel box with steel stiffeners. It contained a 203 mm (8 inch) diameter hole to accept an air duct for pressurizing the chamber. A removable entry hatch was located at the back of the chamber for accessing the samples when the chamber was mounted over a bulkhead. The chamber met the leakage criteria of 1 m<sup>3</sup>/hr at 100 Pa when the chamber was completely sealed as

specified in paragraph 5.1 of Standard ISO 5925/1 1981. The chamber was also designed so static pressure probes could be mounted at the top and bottom elevation of the test samples.

The chamber was pressurized by a blower and damper system designed to blow air into the chamber so as not to directly impinge upon the test samples. The ductwork connecting the blower to the chamber incorporated a laminar flow element to measure the volumetric flow rate. A schematic of the air leakage chamber is provided in Appendix A, Figure A-1. A schematic of the ductwork is provided in Appendix A, Figure A-2.

## **2.2 Furnace**

Underwriters Laboratories Inc.'s vertical furnace is capable of exposing a maximum test specimen of 4.25 m wide by 3.65 m tall (14'-0" x 12'-0"). The furnace is equipped with natural gasdiffusion burners symmetrically placed across the back wall. Windows are located on both sides of the furnace to allow observation of the surface exposed to the flame.

## **2.3 Test Frame**

Figures A-3 and A-4 (Appendix A) show the elevation and construction details of the moveable test frame. The moveable test frame consisted of an outer steel frame and a 330 mm (13 inch) thick masonry wall constructed around the inside perimeter of the steel frame. Bulkhead mounting brackets were positioned along the inside perimeter of the opening. Bulkhead mounting brackets were constructed of 6.35 mm thick (0.25 inch) steel tees and MC12x31 channel.

## **2.4 Bulkheads**

Figures A-5 through A-7 (Appendix A) show the construction details of the bulkhead assemblies. Bulkheads measured 3020 mm wide by 2480 mm high (118.9 by 97.6 inches) and were constructed from 4.5 mm (0.177 inch) thick plate steel as specified in Standard IMO FP 37/22/Add.1 Par. 2.1.1. A 64 mm (2.5 inch) thick ceramic fiber blanket insulation<sup>1</sup> was installed on the unexposed side of the bulkhead to provide an A-60 rating. The insulation had a  $96.1 \text{ kg/m}^3$  ( $6 \text{ lb/ft}^3$ ) density. The insulation was anchored to the unexposed fire side face by impaling it on 102 mm long, 3 mm diameter (4 inch long by 0.12 diameter) steel pins and securing with locking

---

<sup>1</sup> Fiberfrax Part No. 764521000, 764561000 manufactured by Carborundum, Buffalo, New York.

caps. The pins were pre-welded to the bulkhead face in a staggered 457 mm (18 inch) on-center pattern.

## **2.5 Instrumentation**

### **2.5.1 Data Acquisition**

During the fire tests, temperatures, pressures, and linear displacement of the bulkheads were recorded. Temperatures and pressures were collected at a 2 1/2 minute scan rate using an Autodata 10 electronic data acquisition system. Linear displacement of the bulkheads was measured with a graduated ruler and recorded manually.

During the leakage tests, temperatures, flow rates, and pressures were recorded manually.

### **2.5.2 Fire Test - Furnace Temperatures**

The furnace thermocouples were constructed and positioned in accordance with Standard IMO FP 37/22 Add. 1 Par 7.2 through 7.4. The thermocouples consisted of a bare bead supported by a ceramic insulator and steel tube. The bead extended 25 mm (1 inch) from the end of the insulator. Type K (Chromel-Alumel) thermocouples with a referenced accuracy of  $\pm 2.2^{\circ}\text{C}$  ( $\pm 4^{\circ}\text{F}$ ) were used. The furnace thermocouple locations are shown in Appendix A, Figure A-8.

### **2.5.3 Fire Test - Furnace Pressure**

The static pressure probes were constructed in accordance with Standard IMO FP 37/22 Add. 1 Figure 5. The T-Probes were positioned at the top, center, and bottom of the bulkhead. The top location was 2480 mm (97.6 inches) from the bottom of the bulkhead and center location was 1240 mm (48.6 inches) from the bottom of the bulkhead. The pressure probes were connected to electronic pressure transducers with an accuracy of  $\pm 2\%$ .

### **2.5.4 Fire Test - Sample Temperatures**

Temperatures of unexposed surfaces were measured using 0.7 mm diameter (0.275 inch), Type K thermocouples, brazed to a copper disc 12 mm (0.47 inch) in diameter and 0.2 mm (0.008 inch) in thickness. The disc was covered with a 30 x 30 x 2 mm (1.18 x 1.18 x 0.08 inch) pad having a

density of 1000 kg/m<sup>3</sup> (62.4 lb/ft<sup>3</sup>). The pads were attached firmly to the surface with a ceramic adhesive. The thermocouples had referenced accuracy of  $\pm 2.2^{\circ}\text{C}$  ( $\pm 4^{\circ}\text{F}$ ).

Figures A-5 through A-7 (Appendix A) show the locations of the thermocouples on the steel bulkheads. Five thermocouples were attached to the unexposed side of each door sample with one in the center and the others in the center of each quarter panel.

#### **2.5.5 Fire Test - Sample Deflection**

The deflection of the door assemblies was measured using a graduated stick ruler from a reference line located at the horizontal centerline of the assembly.

#### **2.5.6 Leakage Test - Volumetric Flow Rate**

The air flow through the test assembly was determined from the pressure differential measured through laminar flow elements. Two flow elements were used depending on the quantity of air flow. The specifications of the laminar flow elements are provided in Table 2. The manufacturer's calibration curves used to convert pressure differential to volumetric flow rate are provided in Appendix B, Figures B-1 and B-2.

**Table 2. Laminar Flow Element Specification**

| No. | Diameter<br>(mm) | Model   | Maximum Flow<br>Range*<br>$\text{m}^3/\text{hr}$ ( $\text{ft}^3/\text{min}$ ) |
|-----|------------------|---------|---|
| 1   | 51               | 50MC2 2 | 175 (103)   |
| 2   | 152              | 50MC2 6 | 1850 (1100)   |

\* measured at  $21^{\circ}\text{C}$  ( $70^{\circ}\text{F}$ ) and 3989 Pa (0.579 lb/ft<sup>2</sup>).

The pressure drop measured across the flow elements was measured using an inclined micromanometer capable of reading pressures with resolution of 0.25 Pa (0.001 inches water column).

### **2.5.7 Leakage Test - Static Pressure Measurements**

The static pressure inside the test chamber was measured using an electronic manometer with a resolution of 1 Pa. Static pressure measurements on the North and South samples were made 100 mm (4 inches) above and 100 mm (4 inches) below the North and South samples respectively.

## **3. SAMPLES**

Tests were conducted on eleven (11) test samples as described in Table 1. Tests were conducted on seven (7) fire doors, two (2) fire dampers, and two (2) fire stops. Each specimen tested was a different design. Whenever possible, samples within a class were procured from different manufacturers.

The following section provides a description of each test sample as well as the installation procedure used.

### **3.1 Sample Construction**

#### **3.1.1 Dampers**

Two dampers were used in this test program. Both dampers measured 457 mm wide by 305 mm high (18 by 12 inches). A 74°C (165°F) UL Listed fusible link assembly was provided for each damper sample.

The Class A Rated Damper (sample 1) was a single blade design and is described in Appendix A, Figures A-9 through A-11.

The UL Classified damper (sample 2) was a two blade design and is described as follows: The frame consisted of identical top and bottom members formed of 2.7 mm (12 Ga.) galvanized steel with tabs folded and inserted into the channels of the 1.5 mm (16 Ga.) galvanized steel sides. The blades were formed from 1.5 mm (16 Ga.) galvanized steel. The minimum overlap of blade to blade along meeting edges was 6.4 mm (0.25 inch). A shaft assembly was provided on each end of each blade. It consisted of 11 mm (0.43 inch) hexagonal shaped steel galvanized axles pushed into blade crimp and blade clip. On one side, the axle was provided with a linkage crank arm.

The overall dimensions of the damper was 305 mm high by 457 mm wide (12 inches high by 18 inches wide). An schematic of the drawing is shown in Figure A-12. Thermocouple locations are shown in Figure A-13.

### 3.1.2 Fire Stops

The two fire stops tested consisted of a pipe penetration and a cable transit as shown in Appendix A, Figure A-14 and Figure A-15. The pipe penetration utilized two 25.4 mm (1 inch) diameter and one 12.7 mm (0.5 inch) diameter steel conduits. The cable transit utilized a bundle of five lengths of 500 kcmil power cable and a bundle of 54 lengths of 25 pair phone cables. A USCG Class A approved silicone foam sealing compound<sup>2</sup> was used for both fire stops. The total thickness of the finished sealing compound was 194 mm (7.6 inches).

### 3.1.3 Doors

The seven doors used in this test program were obtained from two manufacturers. Appendix A, Figures A-16 through A-19 show the general construction of the doors.

All test doors measured 914 mm in width by 2134 mm in height (35.9 by 84 inches) and all doors incorporated UL Listed hardware. The doors contained a single point cylindrical latch with a 19 mm latch throw. Each door utilized three mortise type steel hinges of the ball bearing type. The hinges were 114 mm high and 4 mm thick. The hinges were attached to the frame with steel screws.

Three A-0 rated doors were tested. Sample 5 was a plate steel door constructed from 3 mm (11 Ga.) plate steel. Samples 6 and 7 were constructed from 1.5 mm (16 Ga.) steel face sheets and 0.91 mm (20 Ga.) steel stiffeners with no insulation.

The two A-15 rated doors were constructed similar to the A-0 doors but contained 128.1 kg/m<sup>3</sup> (8 lb/ft<sup>3</sup>) Coast Guard approved insulation adequate to insulate the doors for the A-15 rating.

---

<sup>2</sup> Dow Corning Corp 3 6548 Silicone RTV Foam Class A, B and C bulkheads and decks and may also be designated as 3M Fire Barrier 2001.

The two 1 Hour UL Classified fire doors were constructed of 1.2 mm (18 Ga.) steel face sheets and 0.76 mm (22 Ga.) steel stiffeners with 96.1 kg/m<sup>3</sup> (6 lb/ft<sup>3</sup>) density mineral fiber insulation.

### **3.2 Sample Installation**

#### **3.2.1 Dampers**

Each damper was continuously welded to the exposed fire side of a 900 mm (35.4 inch) long and 3.8 mm (0.15 inch) thick spigot. The spigot extended 450 mm (17.7 inch) on each side of the bulkhead. Each spigot was insulated up to the A-60 requirement. Each damper was installed in the open position.

#### **3.2.2 Fire Stops**

The cable and pipe penetrations were positioned in the spigot duct openings. The fire stop sealant was prepared and applied to the openings in accordance with the manufacturer's installation instructions. The fire stop sealant was then allowed to cure before testing.

#### **3.2.3 Fire Doors**

Each door sample was welded to the exposed side of the bulkhead with 102 mm (4 inch) long welds spaced 458 mm (18 inch) on-center around the door frame perimeter. The doors were received and installed pre-hung. The average clearances of the doors were confirmed as 2.4 mm (0.09 inch) along the latch and hinge jambs and top edge and 13 mm (0.5 inch) along the bottom.

## **4. TEST PROCEDURE**

### **4.1 Pre-Fire Test Air Leakage**

The following procedure was used to test the air leakage for each bulkhead.

1. The air leakage chamber was clamped and sealed to the MC12 x31 channels.
2. All samples were individually sealed with a clear plastic membrane and tape.

3. The chamber leakage was measured at the static pressures shown in Table 3. The leakage was measured by adjusting the air flow rate through the laminar flow element until the desired static pressure was measured in the leakage chamber. The pressure differential across the laminar flow element was then recorded.
4. The clear plastic membrane and tape was removed from one of the test samples.
5. The leakage was measured at the static pressure levels shown in Table 3. The leakage was measured by adjusting the variable speed blower attached to the laminar flow element until the desired static pressure was measured in the leakage chamber. The pressure differential across the laminar flow element was then recorded.
6. The sample was resealed with clear plastic membrane and tape.
7. Steps 4 through 6 were repeated for each test sample in the bulkhead.
8. After each individual sample was tested, the samples were again sealed off, and the chamber leakage was measured.
9. After the leakage tests, all tape and clear plastic membrane used to stop leakage through the samples were removed.

**Table 3. Leakage Test Static Pressure Levels**

| No. | Pressure<br>Pa. (lb/ft <sup>2</sup> ) |
|-----|---------------------------------------|
| 1   | 5 (0.1)                               |
| 2   | 10 (0.2)                              |
| 3   | 20 (0.4)                              |
| 4   | 30 (0.6)                              |
| 5   | 50 (1.0)                              |
| 6   | 70 (1.5)                              |
| 7   | 100 (2.0)                             |
| 8   | 5 (0.1)                               |
| 9   | 100* (2.0)                            |

\* When the leakage rate at 100 Pa was too high for the instrumentation, the last leakage reading was taken at the highest possible static pressure.

#### **4.2 Fire Test**

During the fire test, the furnace was controlled in accordance with Standard ISO 834. The pressure inside the furnace was controlled in accordance with Standard IMO FP 37/22/Add.1.

The unexposed surface temperatures of the doors and bulkheads were recorded and averaged.

The tests were conducted for a duration of one hour.

Visual observations were recorded for each test and the deflections of the assembly toward the furnace were measured from a reference line. The reference line was positioned along the horizontal centerline of the assembly, and the deflection readings were typically recorded at three locations. Maximum door separations from the door frame were recorded and a cotton pad test was conducted on the hot gases that were emitted through the separations. A gap gage was used during the tests to determine if a separation greater than 6 mm (0.24 inch) developed.

#### **4.3 Post Fire Test Air Leakage**

After exposure to the one-hour fire test, samples were allowed to cool for a minimum of 12 hours until they were cool to the touch. They were then subjected to the air leakage test as specified in Section 4.1 of this report.

### **5. TEST RESULTS AND DISCUSSION**

The results for each fire test are summarized below. Each bulkhead is listed with specific items about the performance of the test samples as required by the Test Standard.

#### **5.1 Fire Tests**

Five furnace tests were conducted. The test sample locations in the bulkheads are described in Table 1. The schedule of tests is shown in Table 4.

**Table 4. Test Schedule**

| Bulkhead | Test Date |
|----------|-----------|
| A        | 5/12/94   |
| B        | 5/17/94   |
| C        | 5/24/94   |
| E        | 6/7/94    |
| D        | 6/22/94   |

Furnace temperatures and pressures are reported in Appendix C. Unexposed surface temperatures are provided in Appendix D. Observations and sample deflections are provided in Appendix E.

### **5.1.1 Furnace Performance**

During the tests, the temperatures inside the furnace were controlled in accordance with Standard ISO 834. Figures C-1 through C-5 in Appendix C show the average furnace temperatures recorded during the fire tests compared to the ISO 834 temperature curve.

The pressure inside the furnace was controlled in accordance with Standard IMO FP 37/22/Add.1. Figures C-6 through C-10 (Appendix C) show the pressures recorded during the fire tests.

### **5.1.2 Bulkheads**

Table 5 in Section 5.1.8 shows a summary of the bulkhead fire test results. The deflections measured in the bulkheads during the fire tests are tabulated in Appendix E. Plots of the temperatures measured on the unexposed side of the bulkheads are shown in Figures D-1 through D-5 located in Appendix D.

### **5.1.3 Fire Dampers (Samples 1 and 2)**

The following is a summary of the results of the Fire Damper tests.

- No flaming occurred on the unexposed side of the fire stop penetration samples during the fire endurance test.
- It was not possible to insert a 6 mm (0.24 inch) gap gauge into any openings in the specimens.
- The cotton pad tests conducted on the hot gases that were generated resulted in no ignition.
- No through openings developed in either sample.

### **5.1.4 Fire Stops (Samples 3 and 4)**

The following is a summary of the results of the Fire Stop tests.

- No flaming occurred on the unexposed side of the fire stop penetration samples during the fire endurance test.
- It was not possible to insert a 6 mm (0.24 inch) gap gauge into any openings in the specimens.
- The cotton pad tests conducted on the hot gases that were generated resulted in no ignition.

- At 13:35 min:sec, the temperature rise above ambient at a single point on the unexposed surface of the cable transit exceeded 180°C (356°F).
- The unexposed temperature rise of the pipe penetration surface did not exceed 180°C (356°F) at a single point during the 1 hour fire test.

#### **5.1.5 A-0 Rated Fire Doors (Samples 5, 6, and 7)**

The following is a summary of the results of the A-0 Fire Door tests.

- Steady flaming occurred from Sample 5 at 35:00 min:sec into the fire test. No flaming occurred on the unexposed side of samples 6 or 7.
- It was not possible to insert a 6 mm (0.24 inch) gap gauge into any openings in the specimens.
- The cotton pad test conducted on Sample 5 at 23:00 min:sec resulted in no ignition. The cotton pad tests conducted on Samples 6 and 7 resulted in no ignition.

#### **5.1.6 A-15 Rated Fire Doors (Samples 8 and 9)**

The following is a summary of the results of the A-15 Fire Door tests.

- There were light intermittent licks of flame along the top edge of Sample 8 at 36:00 min:sec and at the top edge of Sample 9 at 15:00 min:sec.
- It was not possible to insert a 6 mm (0.24 inch) gap gauge into any openings in the specimens.
- The cotton pad tests resulted in no ignition.
- The average unexposed temperature rise did not exceed 140°C (284°F) for either sample for the first 15 minutes of the test.
- One thermocouple on Sample 8 exceeded the 180°C (356°F) limit for a single point at 14:50 min:sec.
- One thermocouple on Sample 9 exceeded the 180°C (356°F) limit for a single point at 14:55 min:sec.

#### **5.1.7 UL Listed 1-Hour Fire Doors (Samples 10 and 11)**

The following is a summary of the results of the UL Listed Fire Door tests.

- No flaming occurred on the unexposed side during the fire test.
- It was not possible to insert a 6 mm (0.24 inch) gap gauge into any openings in the specimens.
- The cotton pad tests resulted in no ignition.

- The average unexposed temperature rise of Sample 10 and Sample 11 exceeded 140°C (284°F) at 14:58 and 12:02 min:sec, respectively.
- Samples 10 and 11 exceeded the 180°C (356°F) single point limit after 11:56 min:sec and 9:30 min:sec, respectively.

### 5.1.8 Summary

Tables 5 and 6 show a summary of the fire test results.

**Table 5. Summary of Bulkhead Results**

| Bulkhead | Time for Average Temperature to Rise 140°C (284°F) Above Ambient (min:sec) | Time for a Single Temperature to Rise 180°C (356°F) Above Ambient (min:sec) | Maximum Unexposed Temperature °C (°F) | Maximum Deflection mm (inch) |
|----------|--|---|---------------------------------------|------------------------------|
| A        | Did Not Exceed   | Did Not Exceed  | 208 (406)                             | 64 (2.5)                     |
| B        | 55:00  | Did Not Exceed  | 209 (408)                             | 38 (1.5)                     |
| C        | 50:00  | Did Not Exceed  | 215 (419)                             | 63 (2.5)                     |
| D        | 52:30  | Did Not Exceed  | 198 (388)                             | 63 (2.5)                     |
| E        | 7:30   | 20:00   | 710 (1310)                            | 80 (3.1)                     |

**Table 6. Summary of Sample Results**

| No | Sample                         | Time for Average Temperature to Rise 140°C (284°F) Above Ambient (min:sec) | Time for a Single Temperature to Rise 180°C (356°F) Above Ambient (min:sec) | Maximum Unexposed Temperature °C (°F) | Maximum Deflection mm (inch) |
|----|--------------------------------|--|---|---------------------------------------|------------------------------|
| 1  | Fire Damper (Class A)          | 36:21  | 34:10   | 296 (565)                             | NA*                          |
| 2  | Fire Damper (UL Listed 1 hour) | 56:15  | 58:40   | 183 (361)                             | NA                           |
| 3  | Fire Stop (Cable Transit)      | 22:36  | 13:35   | 451 (845)                             | NA                           |
| 4  | Fire Stop (Pipe Penetration)   | 27:31  | 13:55   | 453 (847)                             | NA                           |
| 5  | Fire Door (A-0 Rated)          | 4:19   | 4:47  | 749 (1380)                            | 57 (2.2)                     |
| 6  | Fire Door (A-0 Rated)          | 10:42  | 10:59   | 569 (1056)                            | 45 (1.8)                     |
| 7  | Fire Door (A-0 Rated)          | 12:24  | 12:25   | 534 (993)                             | 38 (1.5)                     |
| 8  | Fire Door (A-15 Rated)         | 17:09  | 14:50   | 498 (928)                             | 38 (1.5)                     |
| 9  | Fire Door (A-15 Rated)         | 15:10  | 14:55   | 467 (873)                             | 38 (1.5)                     |
| 10 | Fire Door (UL Listed 1 hour)   | 14:58  | 11:56   | 547 (1016)                            | 32 (1.25)                    |
| 11 | Fire Door (UL Listed 1 hour)   | 12:02  | 9:30  | 606 (1123)                            | 32 (1.25)                    |

## 5.2 Leakage Tests

Figures 1-5 show plots of the leakage rates measured for each sample as a function of static pressure in the leakage chamber. The leakage rates were corrected for chamber leakage by subtracting the average chamber leakage measured before and after each leakage test series. The readings were also corrected for atmospheric conditions using Equation 1 as outlined in the Standard. The uncorrected and corrected leakage rates are in Appendix F.

$$Q_a^* = Q_a \left( \frac{P_a + \Delta P}{101325} \right) \left( \frac{293.15}{T_a + 273.15} \right) \left[ 1 - 0.3795 \left( \frac{M_w}{100} \right) \left( \frac{E_s}{P_a + \Delta P} \right) \right] \quad \text{Equation 1}$$

Where:  $Q_a^*$  is the adjusted flow rate.

$Q_a$  is the measured flow rate.

$P_a$  is the barometric pressure, in Pascals.

$\Delta P$  is the pressure increase, in Pascals.

$T_a$  is the air temperature, in Celsius.

$M_w$  is the relative humidity, as a percentage.

$E_s$  is the saturated water vapor pressure, in Pascals.

Three of the door samples (samples 5, 7, and 11) became unlatched during the cool down period after the fire tests. These doors were pushed closed by hand to a friction fit and locked in place with a wooden wedge at the sill before the leakage tests were conducted.

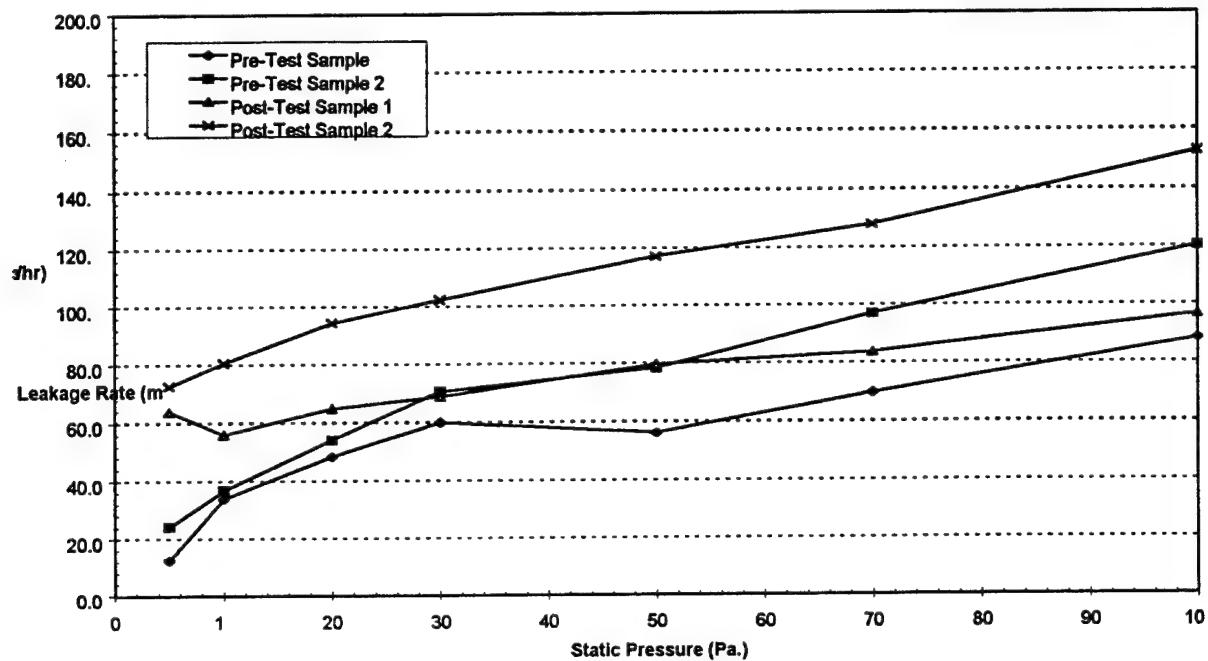


Figure 1. Fire Damper Leakage Rates

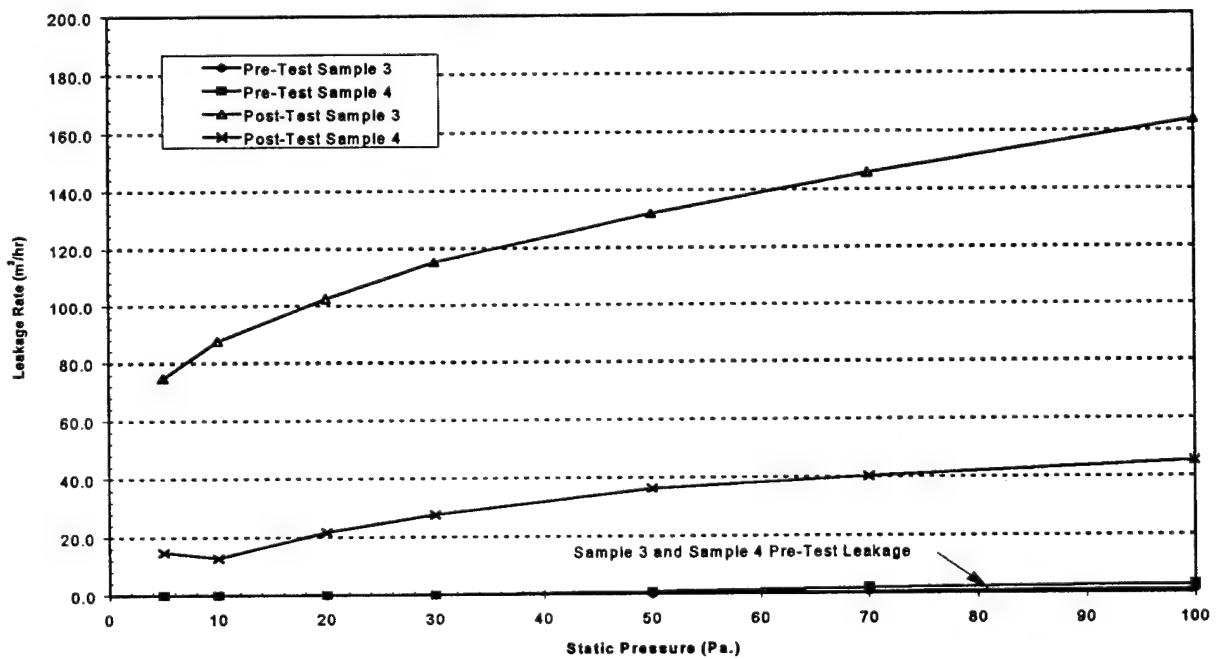


Figure 2. Fire Stop Leakage Rates

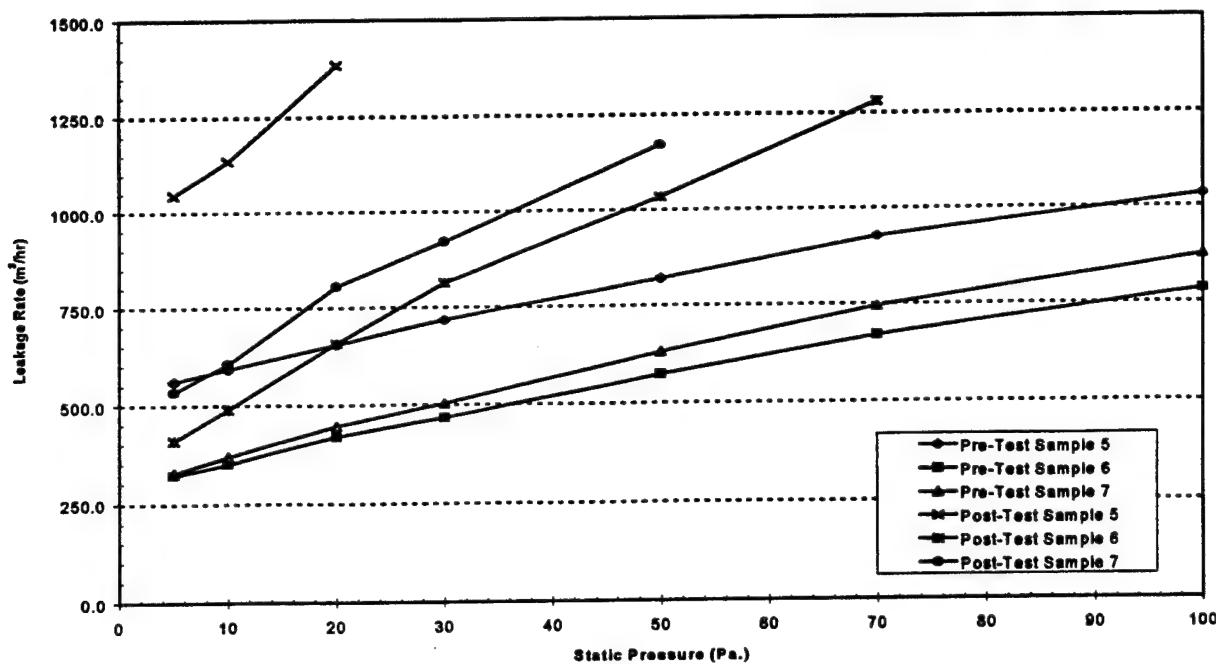


Figure 3. A-0 Fire Door Leakage Rates

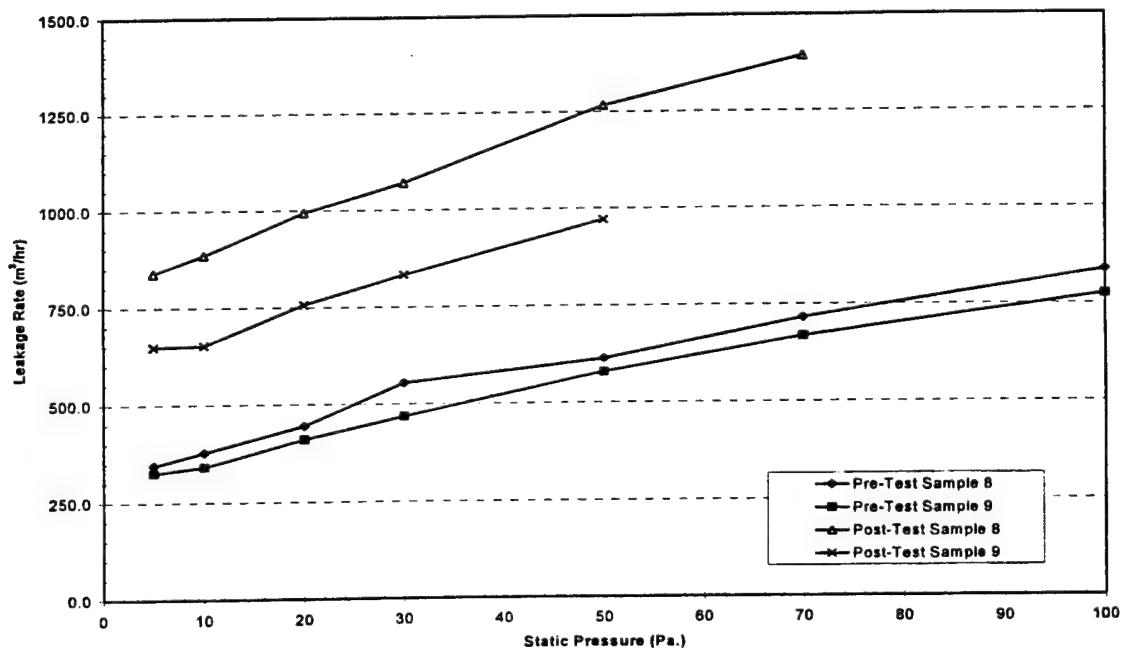


Figure 4. A-15 Fire Doors Leakage Rates

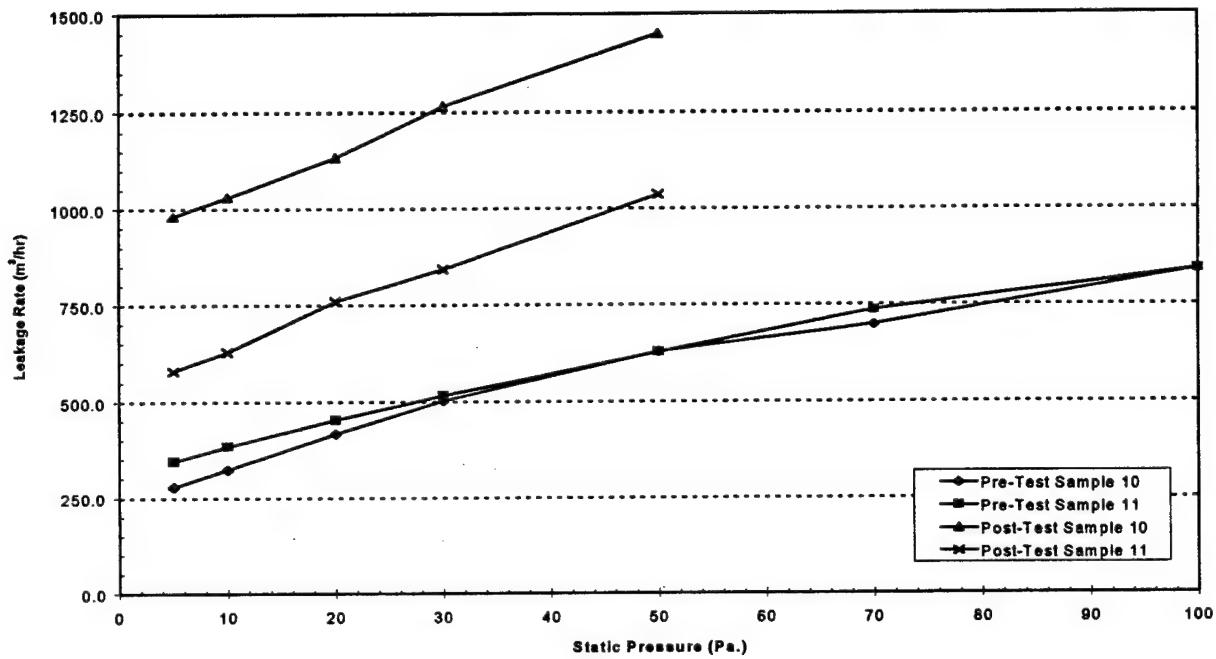


Figure 5. UL Listed 1-Hour Fire Door Leakage Rates

## 6. TEST METHOD CRITIQUE

### 6.1 Fire Test

The fire test standard does not indicate when to stop applying the test for flame penetration. From our understanding and from our discussions with overseas testing agencies, the cotton pad test is not required after the unexposed surface temperature of the specimen exceeds its intended insulation value (i.e., A-15 door exceeds 140°C rise average at 15 minutes). It is the Coast Guard's opinion that the cotton-wool pad test is to verify the integrity of the test specimen. This would identify whether a crack or opening could lead to the passage of hot gases sufficient to cause ignition of combustible material. The acceptance criteria for tests should be to periodically conduct the cotton-wool test for the duration of the test, 60 minutes for class "A" division fixtures.

The fire test method specifies that 30 x 30 mm asbestos pads be placed over the unexposed thermocouples. Asbestos pads can not be used in the United States for health reasons. The standard should be modified to allow a substitute pad material.

## 6.2 Leakage Test

One problem which is not addressed in the leakage test method is the cooling time required after the fire test. We allowed the samples to cool for a minimum of twelve hours after the fire test and did not conduct the leakage test until the assembly was cool to the touch.

Leakage protocol should address the following issues caused by the shifting of the assembly during the cool down period after the fire test.

- What should be the allowable system leakage be after the fire test?
- How can the test samples be prepared for the leakage test? Three of the fire doors in this test series sprung open during the cool down period. The doors were pushed closed to a friction fit, because the locking assemblies were inoperative.

The leakage protocol should address multiple samples in one bulkhead. Testing multiple samples in the same bulkhead reduces testing costs and provides faster turn-around time. When multiple samples are tested in one bulkhead, several procedural questions should be addressed.

- How should each sample be isolated for the leakage test?
- The frequency of chamber leakage measurements should be defined. Should the chamber leakage be measured after each individual sample is tested, or should chamber leakage be measured at the beginning and end of a series of leakage tests on one bulkhead? We feel that the system leakage should be measured before and after each specimen is tested because there was an appreciable difference in the system leakage.
- Where should static pressure measurements be made on bulkheads with multiple samples?

A recommended design for the leakage chamber should be provided. We used a reinforced steel chamber which totally covered the bulkhead and was mounted on the surrounding masonry wall. The advantage of this design is that the tightness of the seal was not affected by bulkhead

deflection.

In order to design the leakage equipment, a maximum leakage rate should be defined. We used a series of laminar flow elements with different ranges to measure the leakage rates of the test samples. On some leakage tests performed after the fire tests, we exceeded the maximum range of our largest flow element when testing at the higher static pressure ranges.

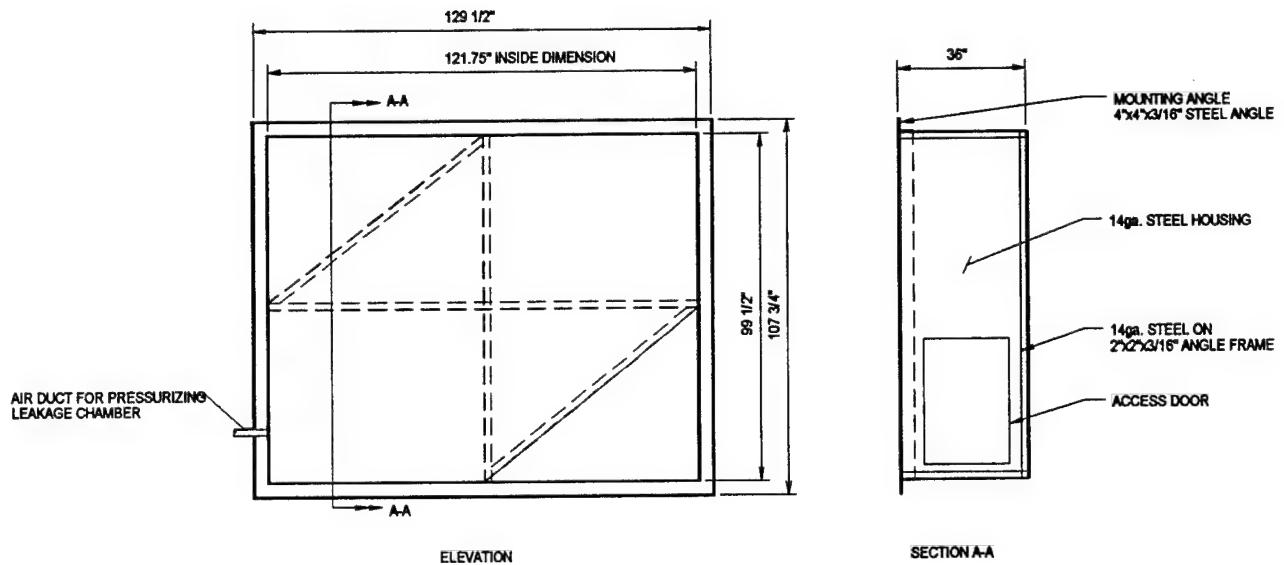
## REFERENCES

- 1 UL 1581 - Reference Standard for Electrical Wires, Cables, and Flexible Cords, 2nd Ed., Underwriters Laboratories, Northbrook, IL, 1991.
- 2 IMO Resolution A.517(13), Recommendation on Fire Test Procedures of "A", "B", and "F" Class Divisions, International Maritime Organization, London, UK.
- 3 DTCG39-93-F-E00676 (DO 0008) Statement of Work, Section 3.3, June 18, 1993.
- 4 Fire Tests-Evaluation of Performance of Smoke Control Door Assemblies - Part 1: Ambient Temperature Test (ISO 5925/1 1981 (E)).
- 5 Revised Recommendation on Fire Test Procedures for "A", "B", and "F" Class Divisions (Annex 2 of FP37/22/Add.1).
- 6 Van Wylen and Sontag, Fundamentals of Classical Thermodynamics, 2nd Ed. John Wiley and Sons Inc., New York, 1973.

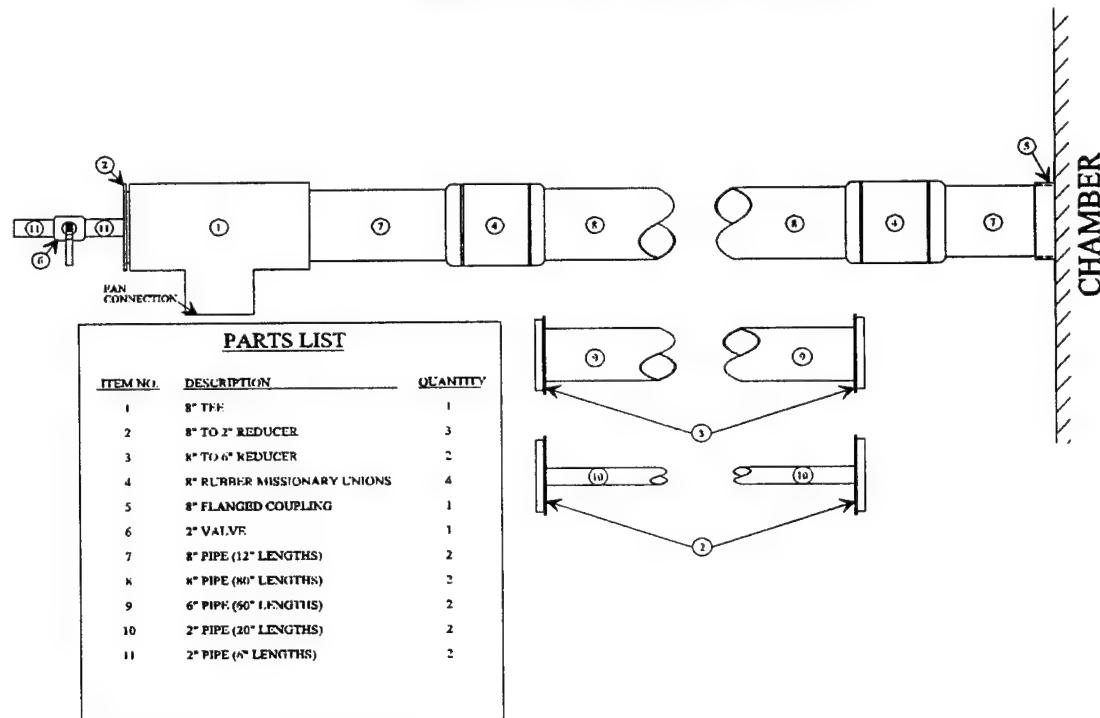
- 1      UL 1581 - Reference Standard for Electrical Wires, Cables, and Flexible Cords, 2nd Ed., Underwriters Laboratories, Northbrook, IL, 1991.
- 2      IMO Resolution A.517(13), Recommendation on Fire Test Procedures for "A", "B", and "F" Class Divisions., International Maritime Organization, London, UK.
- 3      DTCG39-93-F-E00676 (DO 0008) Statement of Work, Section 3.3 June 18. 1993.
- 4      UL 1581 - Reference Standard for Electrical Wires, Cables, and Flexible Cords, 2nd Ed., Underwriters Laboratories, Northbrook, IL, 1991.
- 4      Fire Tests-Evaluation of performance of smoke control door assemblies - Part 1: Ambient temperature test (ISO 5925/1 1981(E))
- 5      Revised Recommendation on Fire Test Procedures for "A", "B", and "F" Class Divisions (Annex 2 of FP37/22/Add.1)".

## APPENDIX A

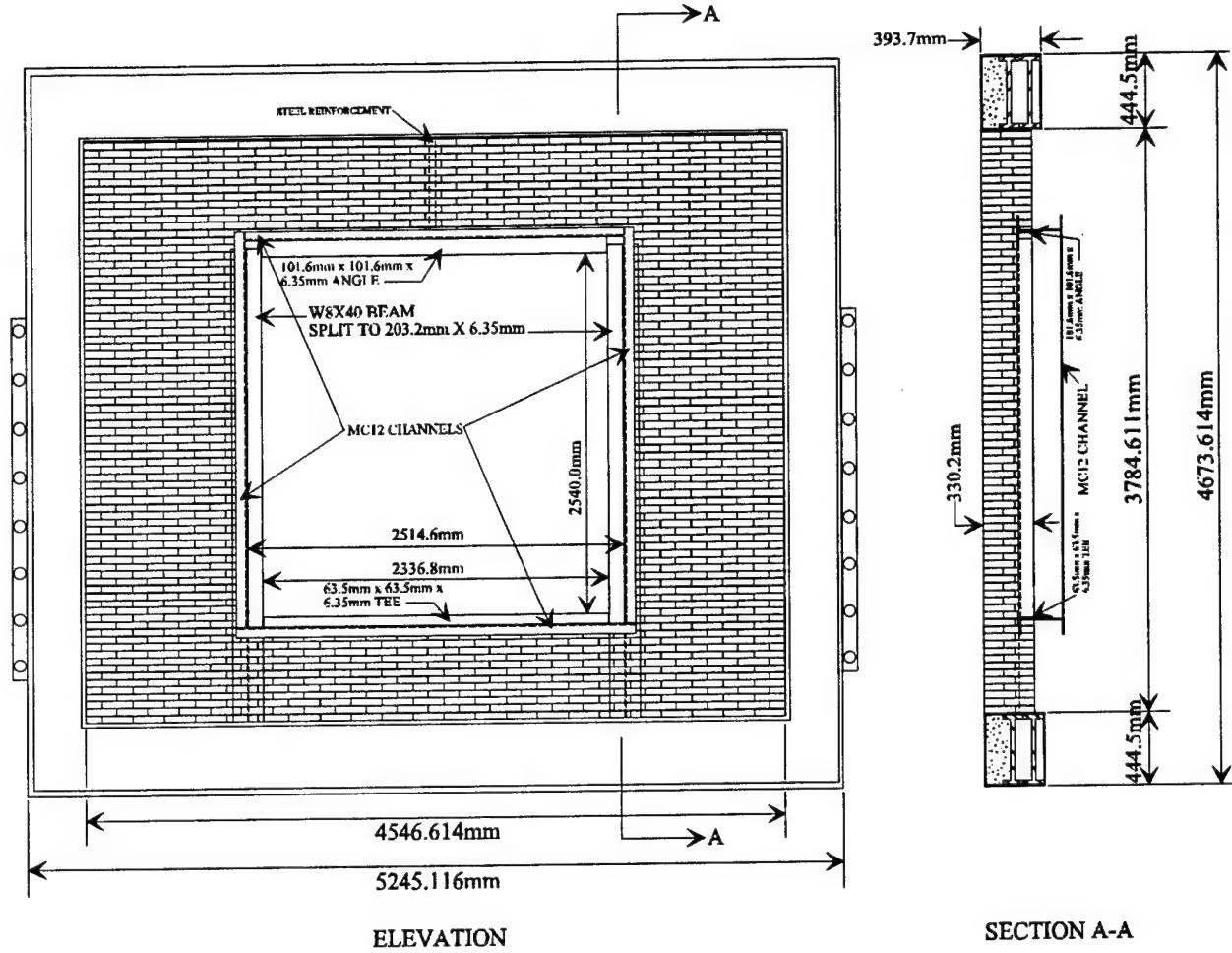
### Construction Details



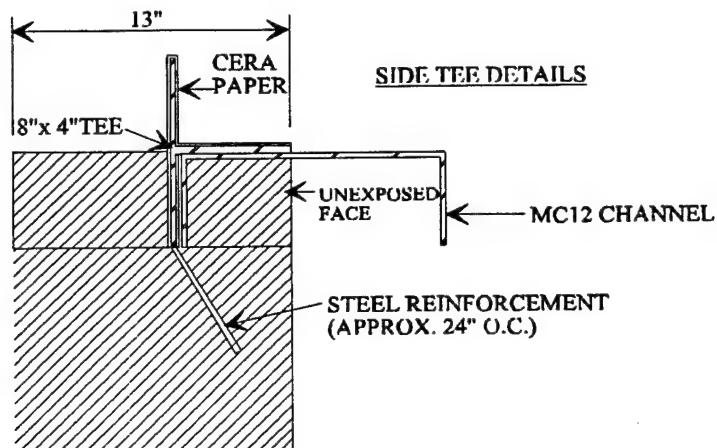
**Figure A-1. Air Leakage Chamber**



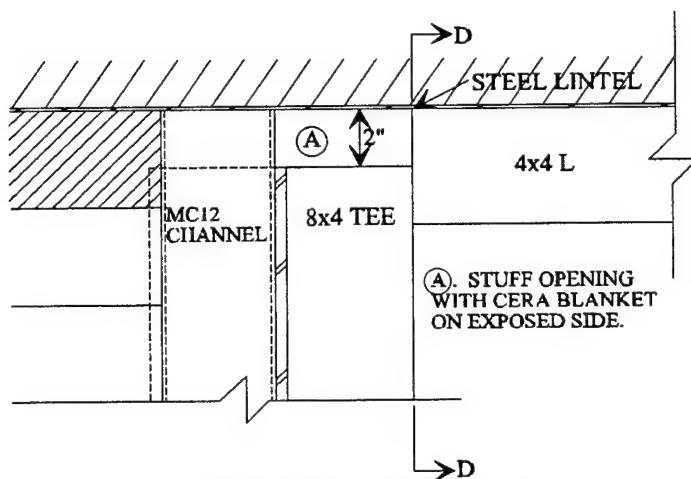
**Figure A-2. Air Leakage Chamber Ductwork**



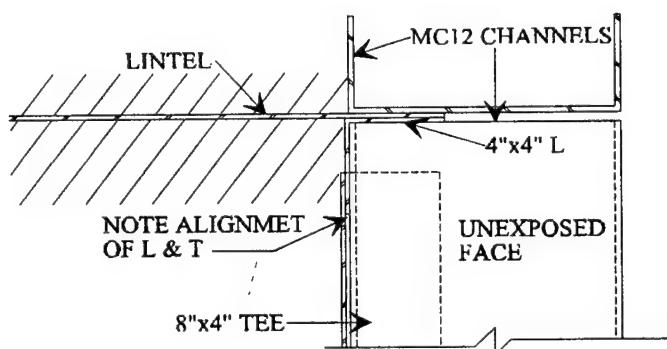
**Figure A-3. Test Wall Assembly**



SECTION B-B : TOP VIEW



REAR VIEW : SECTION C-C



SECTION D-D

Figure A-4. Test Wall Assembly

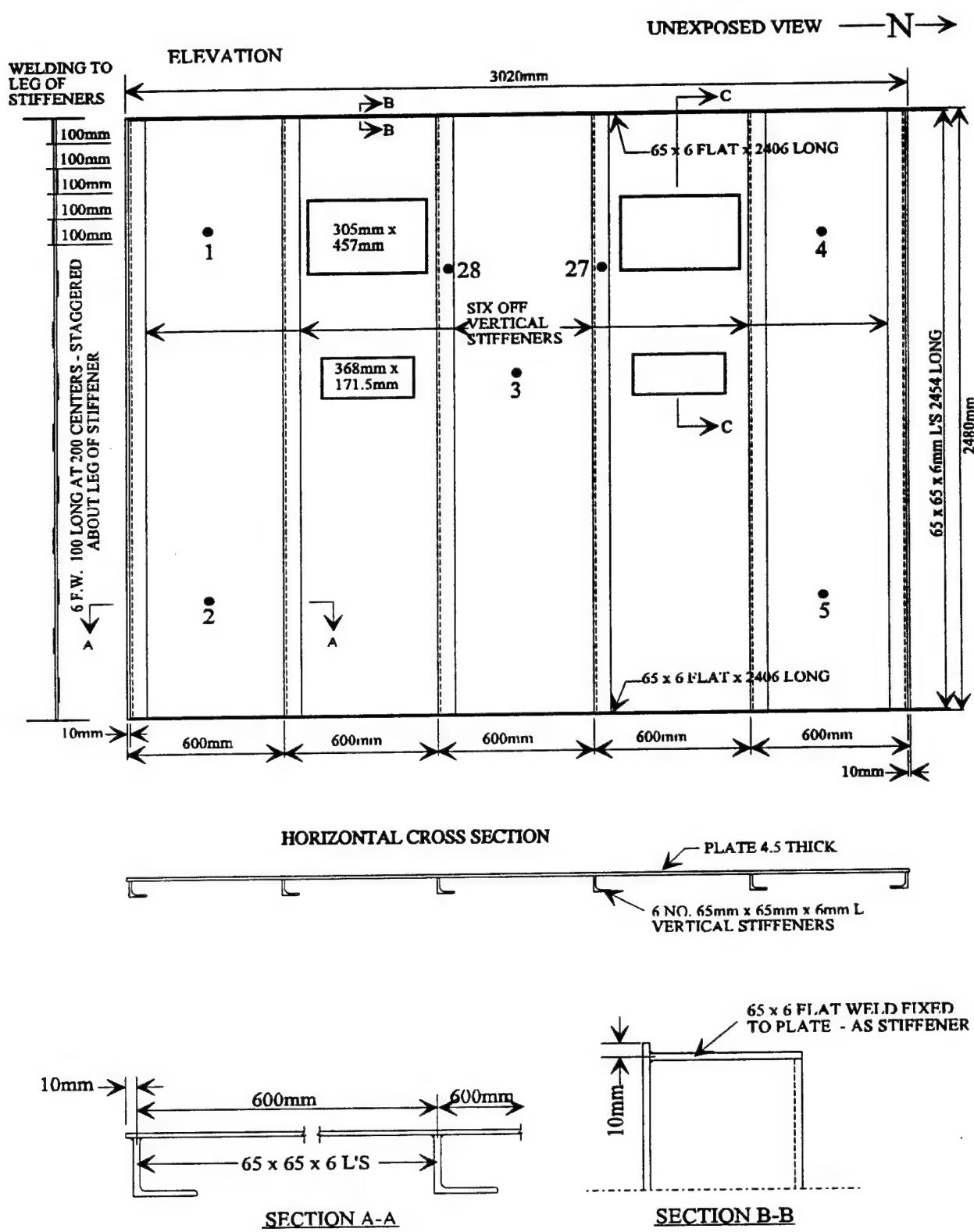
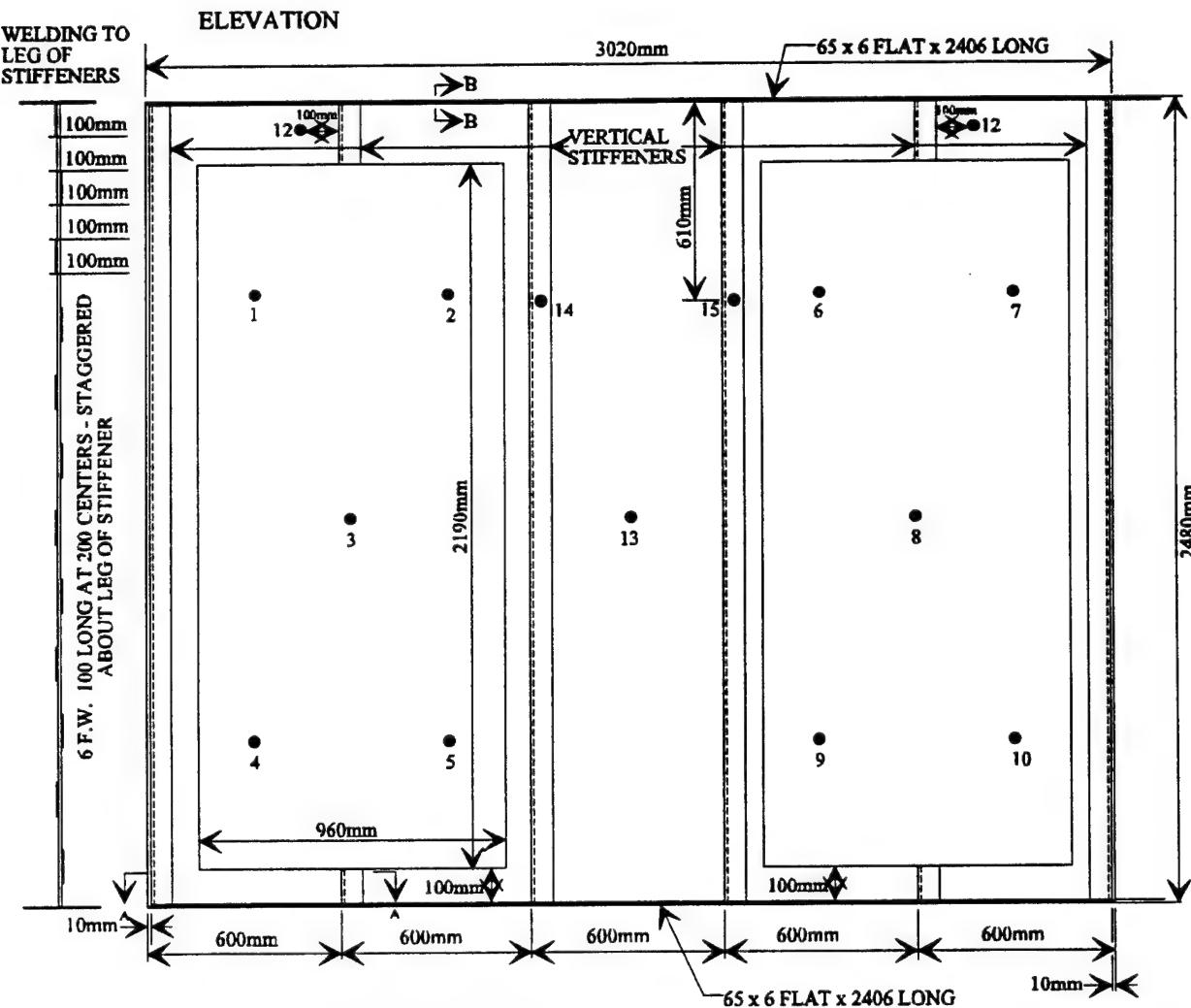
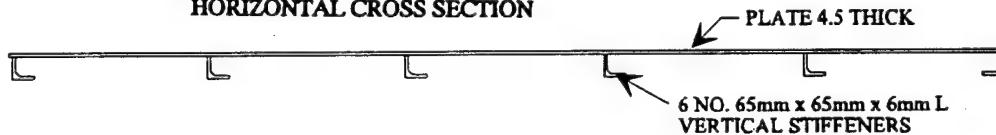


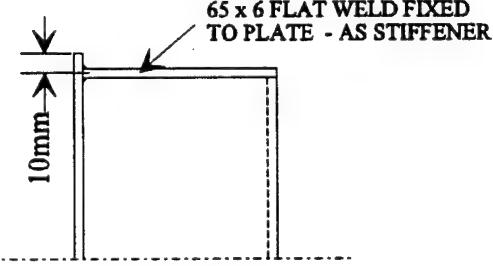
Figure A-5. Bulkhead A



**(EXPOSED SURFACE)  
HORIZONTAL CROSS SECTION**



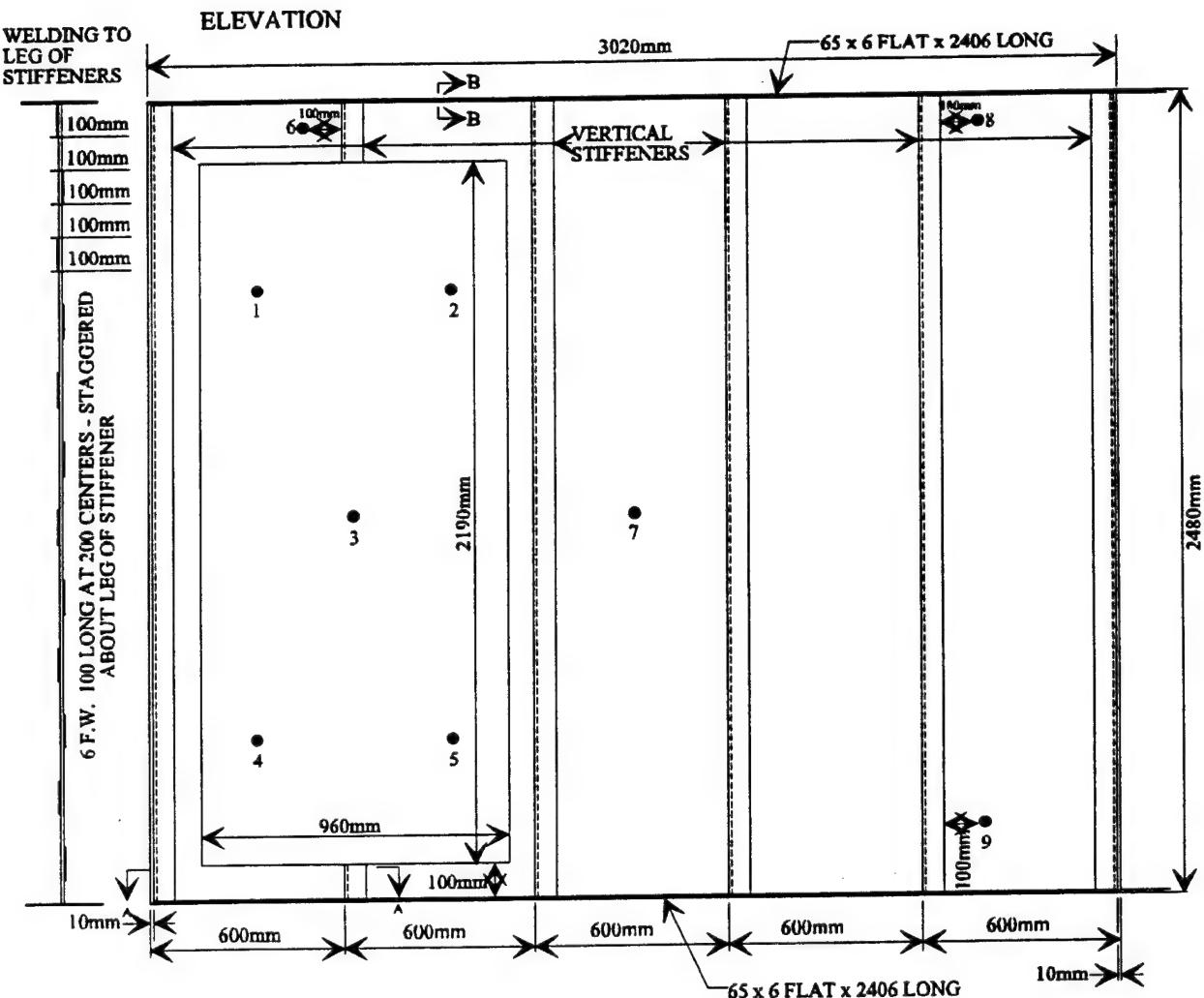
A technical drawing of a U-shaped channel frame. The top horizontal leg is labeled "600mm". The vertical left leg has a thickness of "10mm" indicated by an arrow. The bottom horizontal leg is labeled "65 x 65 x 6 L'S". The right vertical leg has a thickness of "600mm" indicated by an arrow.



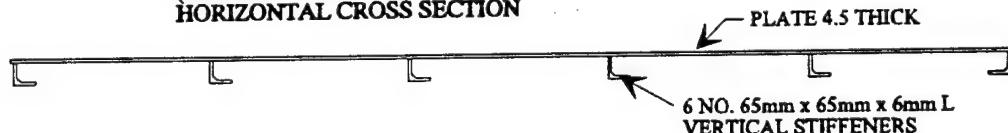
SECTION A-A

## SECTION B-B

**Figure A-6. Bulkheads B through D**



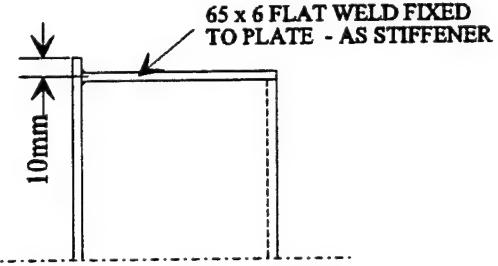
**(EXPOSED SURFACE)  
HORIZONTAL CROSS SECTION**



10mm → | ← 600mm | ← 600mm

65 x 65 x 6 L'S

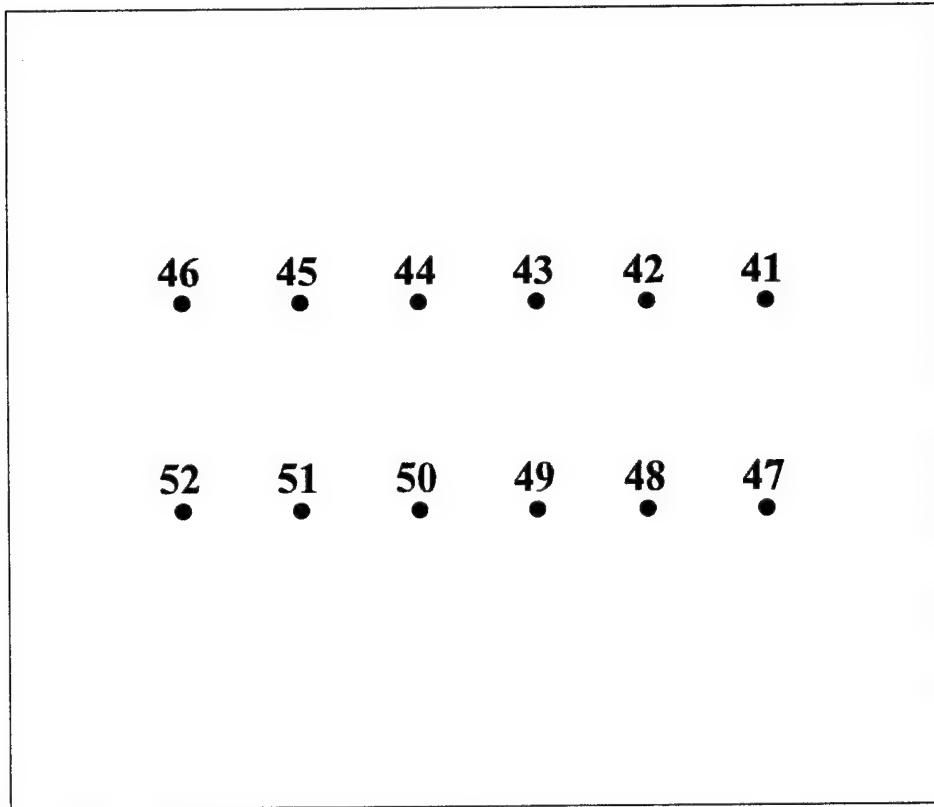
SECTION A-A



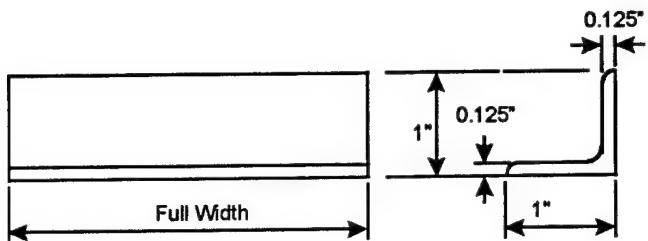
## SECTION B-B

**Figure A-7. Bulkhead E**

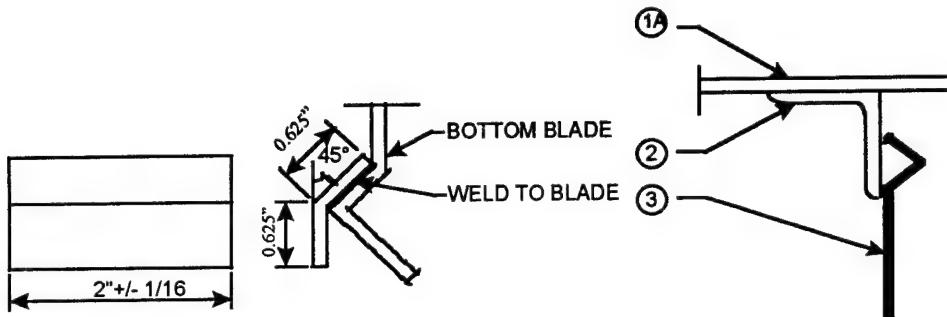
— N —>



**Figure A-8. Furnace Thermocouple Locations**



BLADE STOP - ITEM ②



STRIKER - ITEM ④G

BLADE CLEARANCE  
IN CLOSED POSITION

| BILL OF MATERIALS |  |                |  |
|-------------------|--|----------------|--|
| PART NO           | DESCRIPTION                            | NO. REQUIRED   | MATERIAL                               |
| 1A                | FRAME                                  | 1 PER ASSEMBLY | 2"x1/2"x1/8" CHANNEL H.R. C-1010 STEEL |
| 2                 | BLADE STOP                             | 2 PER ASSEMBLY | 1"x1"x1/8" ANGLE H.R. C-1010 STEEL     |
| 3                 | BLADE                                  | 1 PER ASSEMBLY | 12 GA H.R. C-1010 STEEL                |
| 4                 | BLADE CATCH                            | 1 PER ASSEMBLY | .063 S.S. 1/2 HARD T-301 SS            |
| 4D                | BLADE CATCH MOUNT                      | 1 PER ASSEMBLY | 2"x1/2"x1/8" CHANNEL H.R. C-1010 STEEL |
| 4G                | STRIKER                                | 1 PER ASSEMBLY | 14 GA. H.R. C-1010 STEEL               |
| 5                 | FUSIBLE LINK                           | 1 PER ASSEMBLY | VARIOUS UL LISTED                      |
| 6                 | FUSIBLE LINK BRACKET                   | 2 PER ASSEMBLY | 1/8"x1/2" H.R. C-1010 STEEL            |
| 7                 | SPRING                                 | 1 PER ASSEMBLY | .54 STAINLESS T-301 SS                 |
| 8                 | SPRING BRACKETS                        | 2 PER ASSEMBLY | 16 GA H.R. C-1010 STEEL                |
| 9                 | BEARING SHAFT                          | 2 PER ASSEMBLY | 1/2" DIA. COLD ROLLED C-1010 STEEL     |
| 10                | BUSHING                                | 2 PER ASSEMBLY | SINTERED BRONZE                        |
| 11                | BEARING STRAP W/1/4"-28x1/2" SET SCREW | 2 PER ASSEMBLY | 1/8"x1" HOT ROLLED C-1010 STEEL        |
| 18                | SLEEVE                                 | 1 PER ASSEMBLY | 16 GA H.R. C-1010 STEEL                |
| 19B               | MOUNTING ANGLE                         | 8 PER ASSEMBLY | 1-1/2"x1-1/2"x18 ga. C-1010 STEEL      |

Figure A-9. Damper Construction (Sample 1)

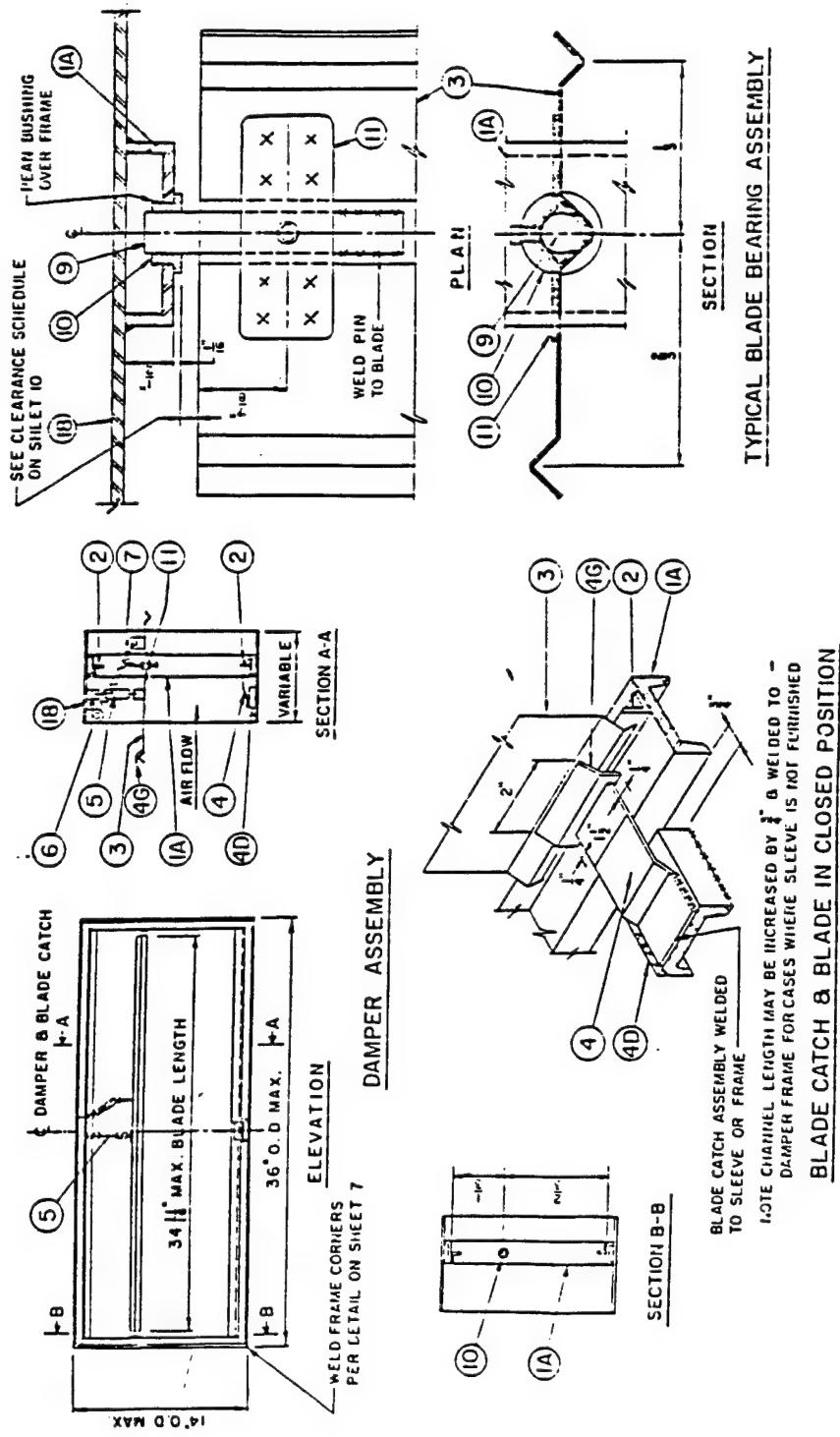
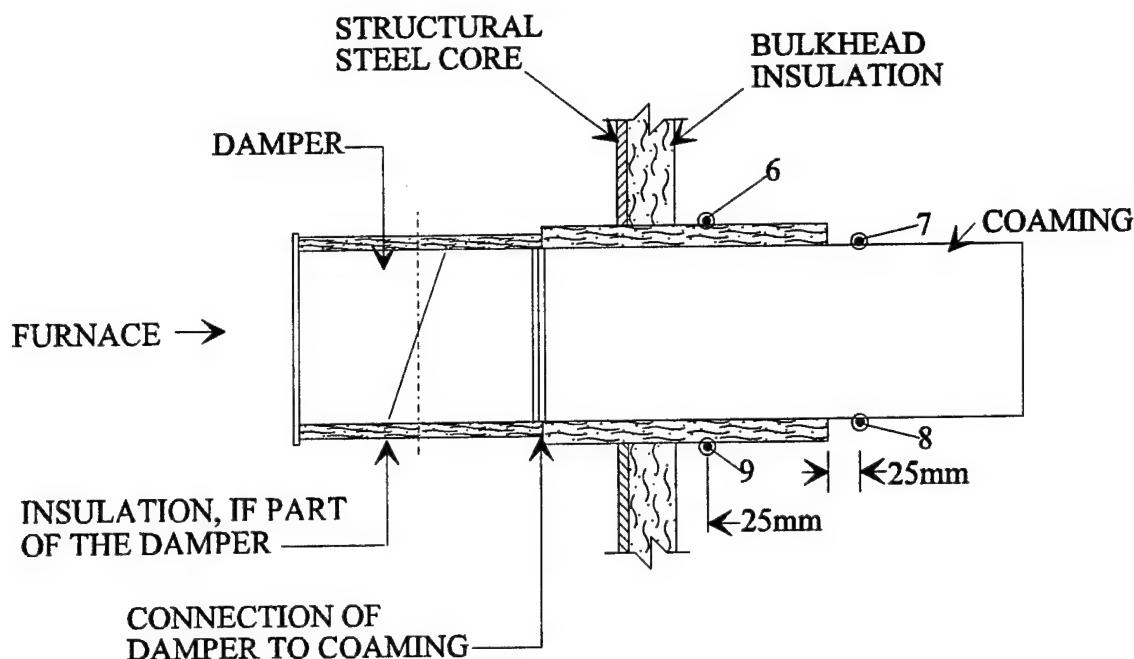
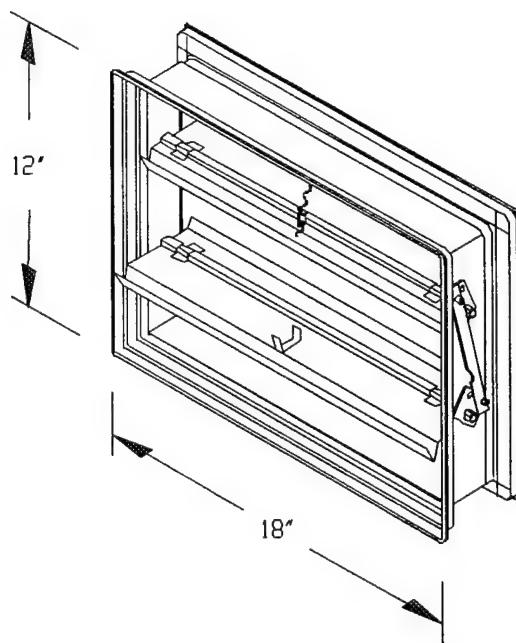


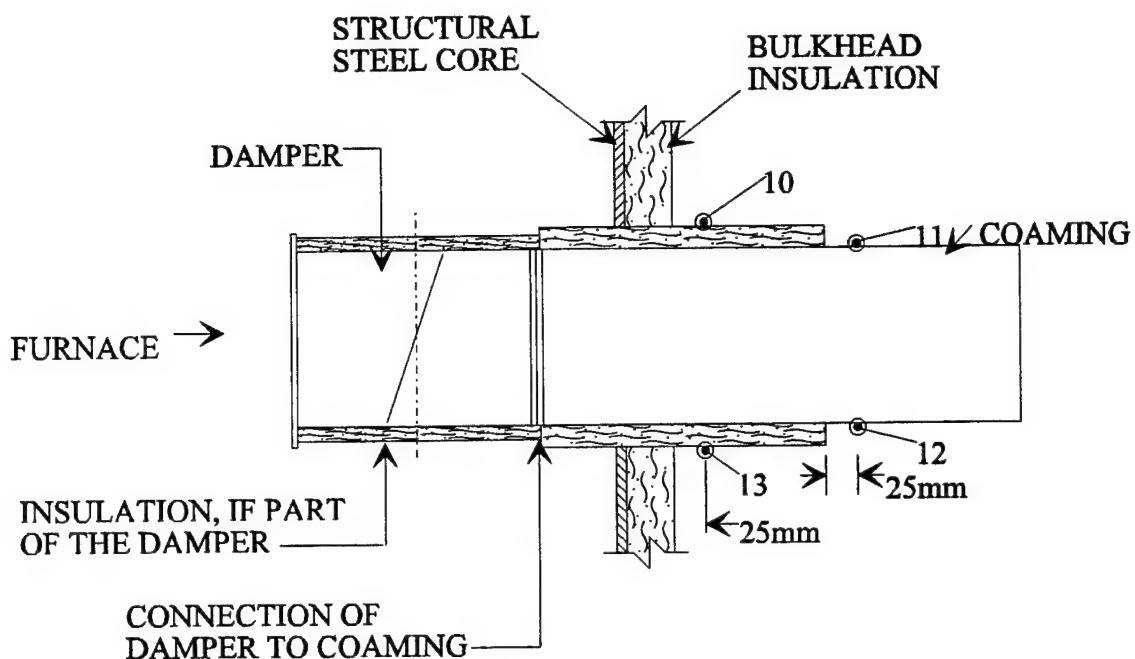
Figure A-10. Damper Construction (Sample 1)



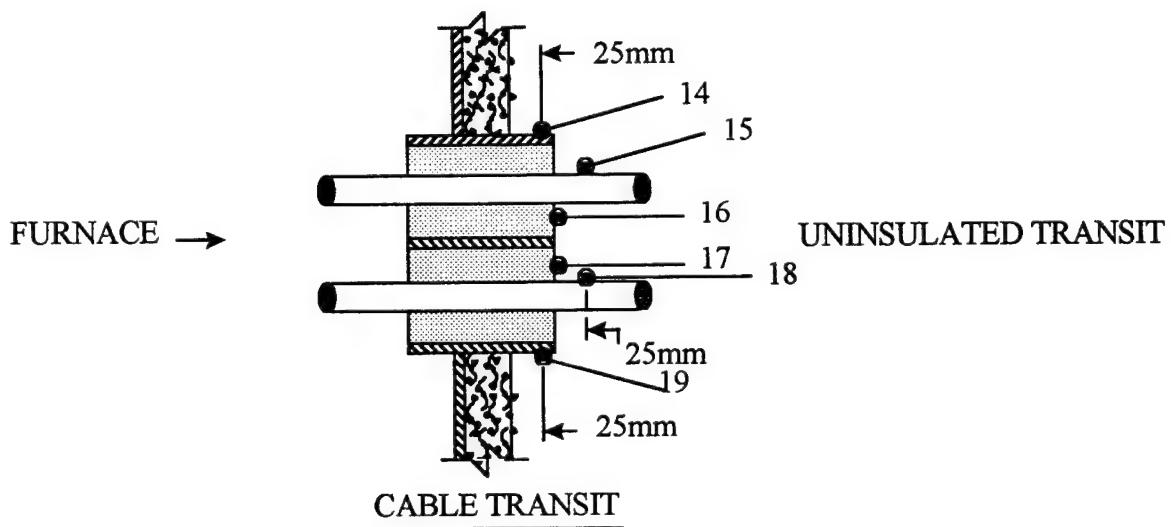
**Figure A-11. Damper Thermocouple Locations (Sample 1)**



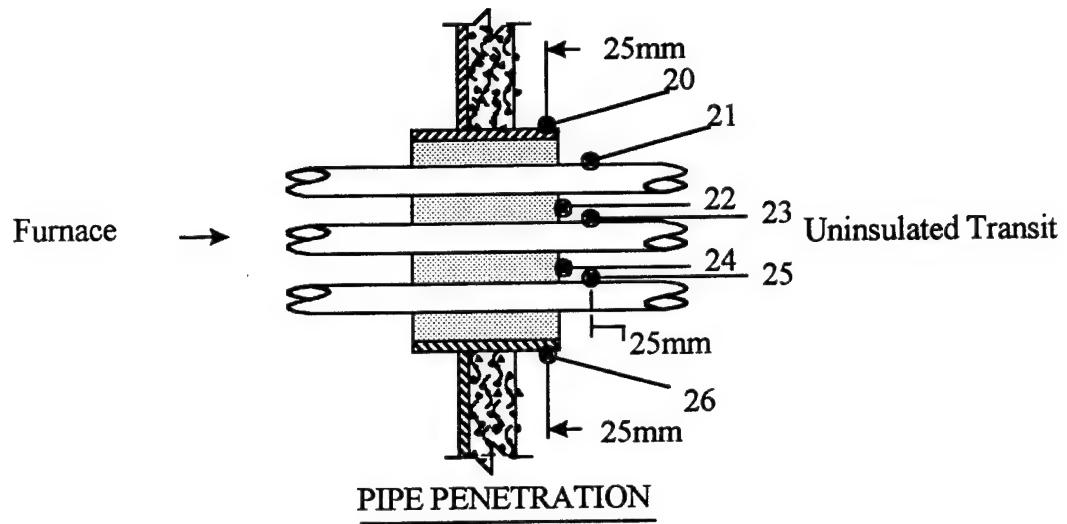
**Figure A-12. Damper Schematic (Sample 2)**



**Figure A-13. Damper Thermocouple Locations (Sample 2)**



**Figure A-14. Fire Stop Thermocouple Locations (Sample 3)**



**Figure A-15. Fire Stop Thermocouple Locations (Sample 4)**

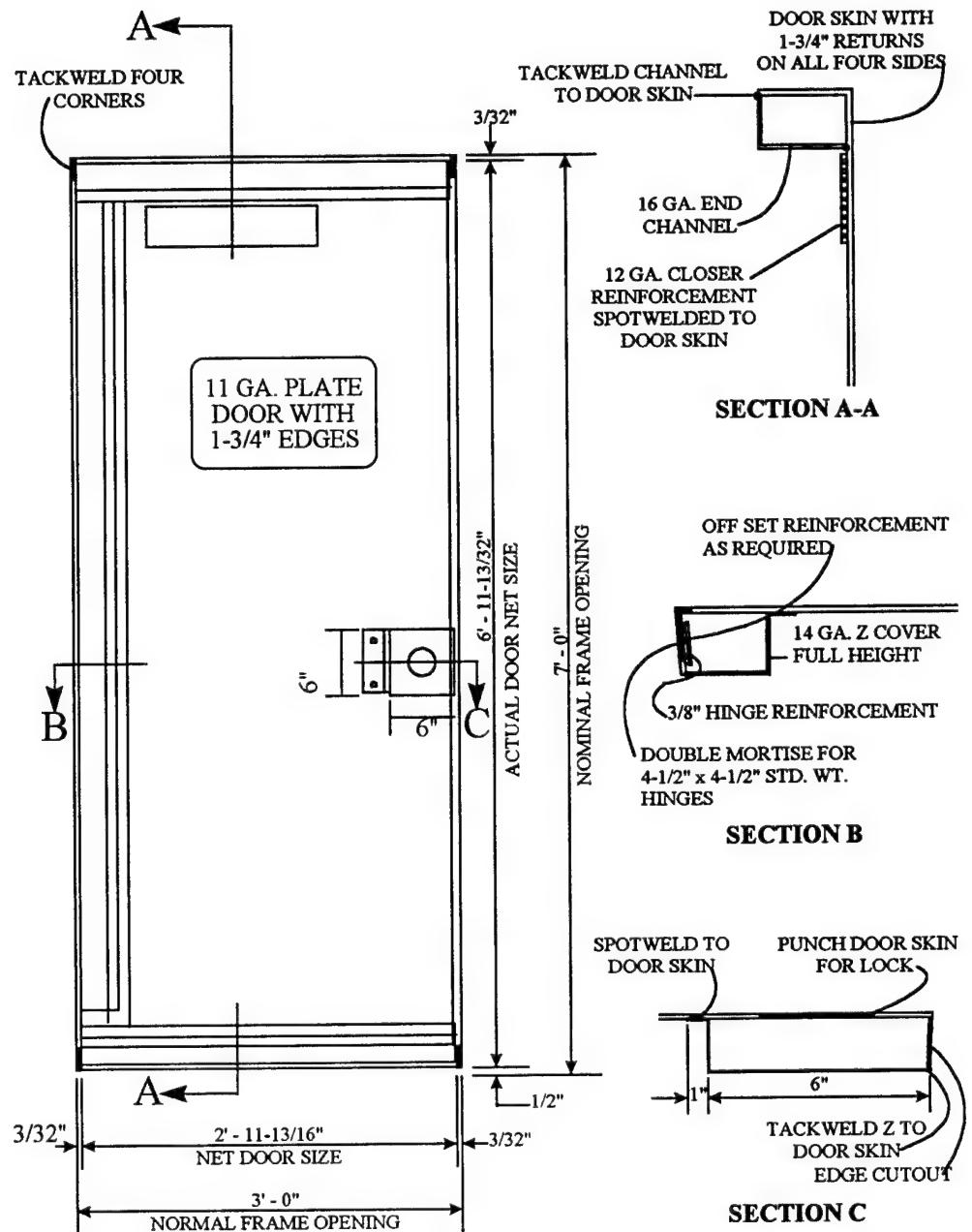


Figure A-16. Door Construction: Sample 5

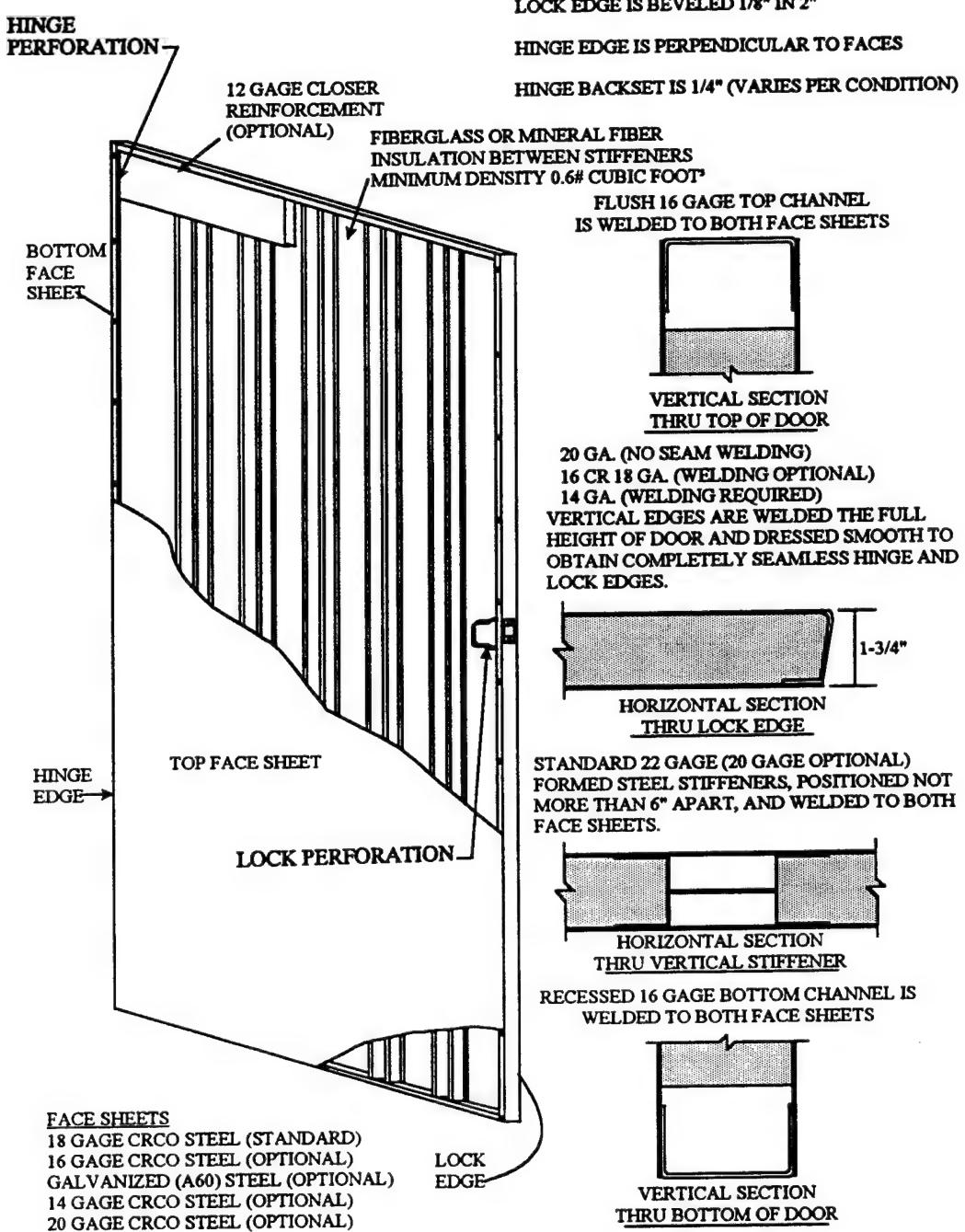
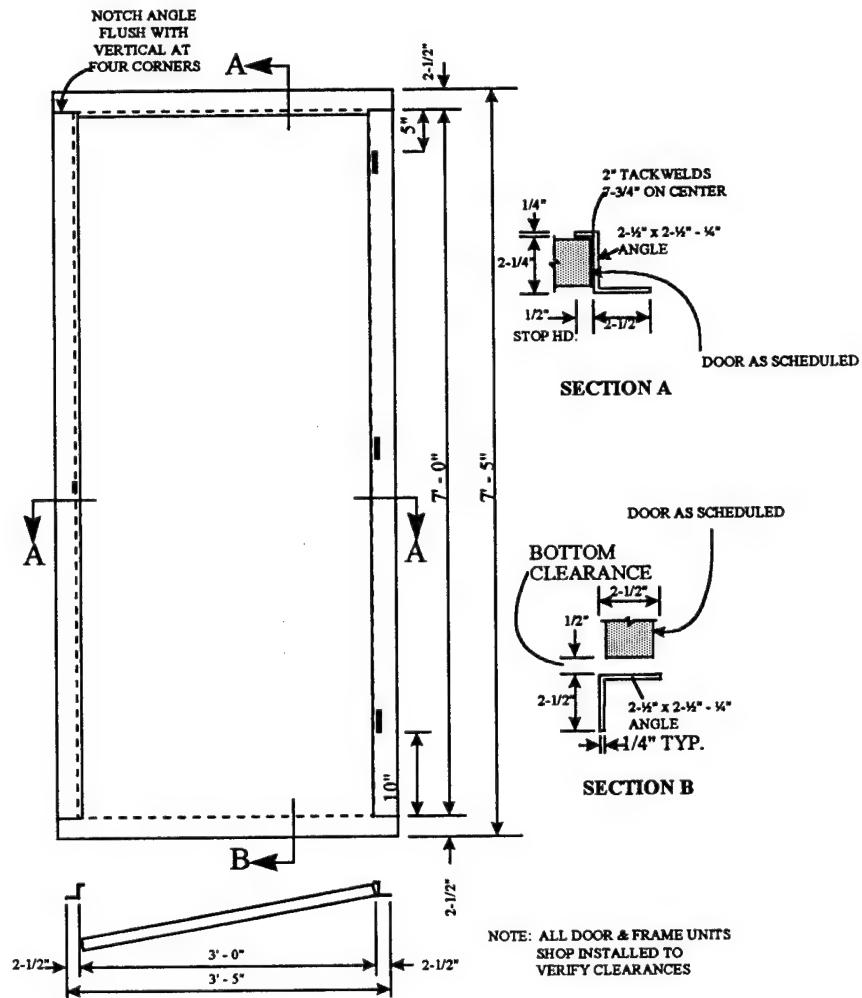
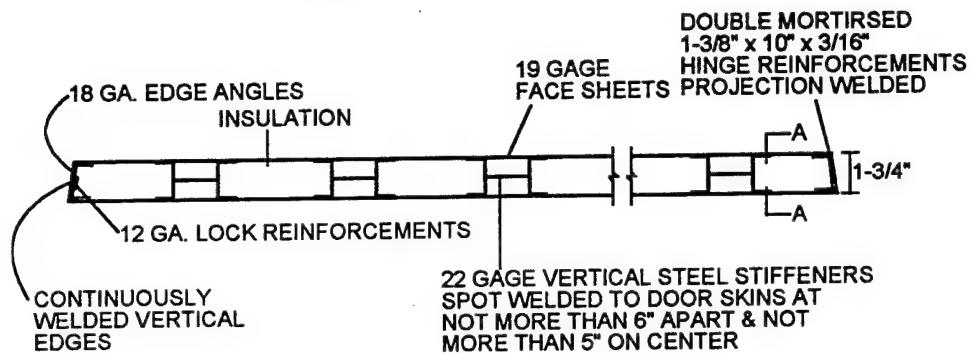


Figure A-17. Door Construction: Samples 7, 8, and 10

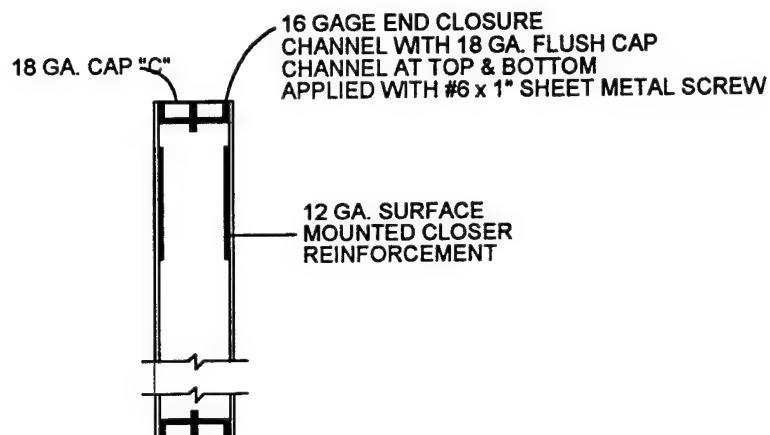


**Figure A-18. Door Construction: Samples 6, 9 and 11**

**ALL DOORS WITH RHR SWING**



**HORIZONTAL SECTION**



**SECTION A-A**

**Figure A-19. Door Construction: Samples 6, 9 and 11**

## Appendix B

### Calibration Information

**Table B-1. Laminar Flow Element Specification**

| No. | Diameter (mm) | Model   | Maximum Flow Range*    | Calibration |
|-----|---------------|---------|------------------------|-------------|
| 1   | 51            | 50MC2 2 | 175 m <sup>3</sup> /h  | Figure B-1  |
| 2   | 152           | 50MC2 6 | 1850 m <sup>3</sup> /h | Figure B-2  |

\* measured at 21°C and 3989 Pa

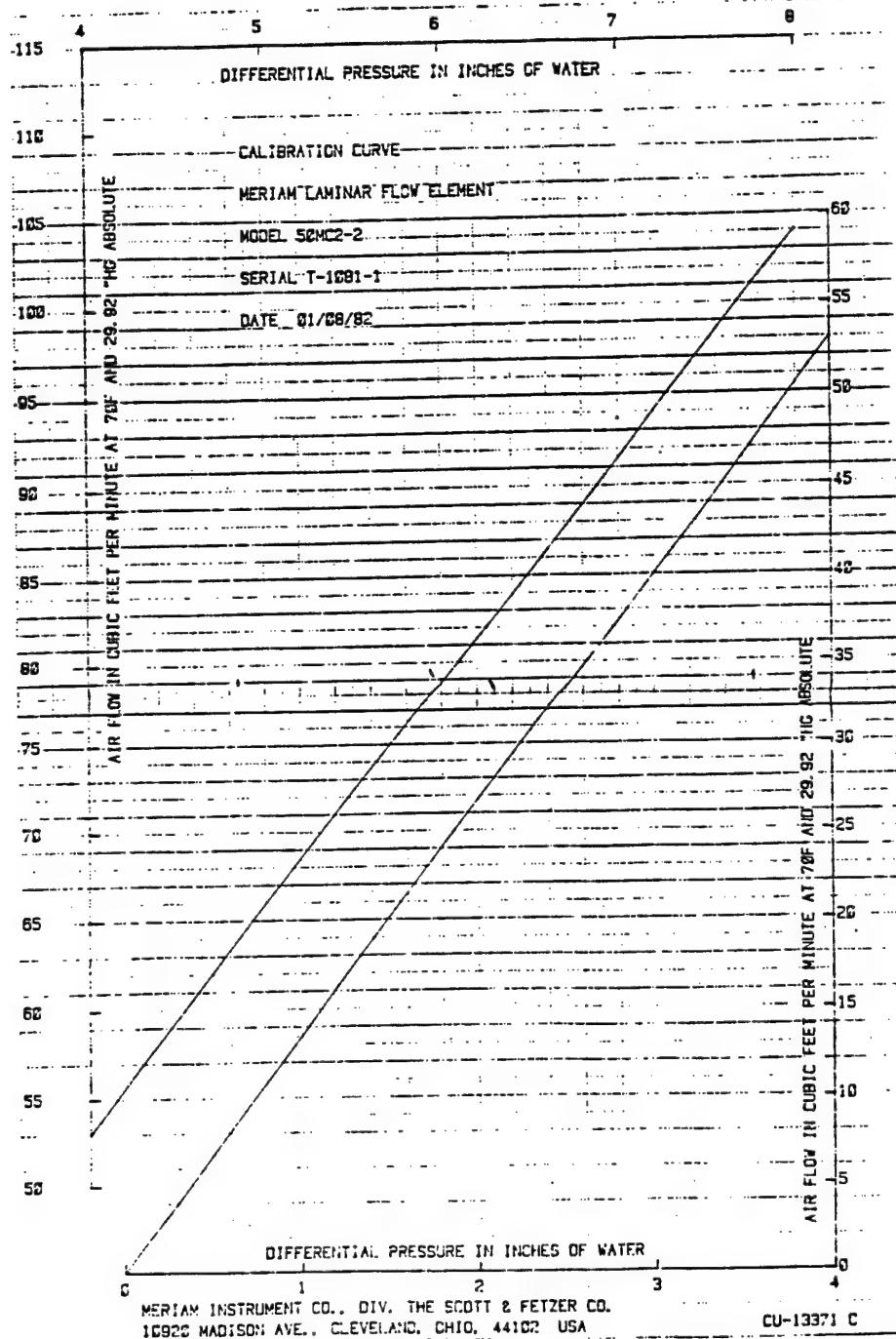


Figure B-1. Laminar Flow Element Calibration Sheet

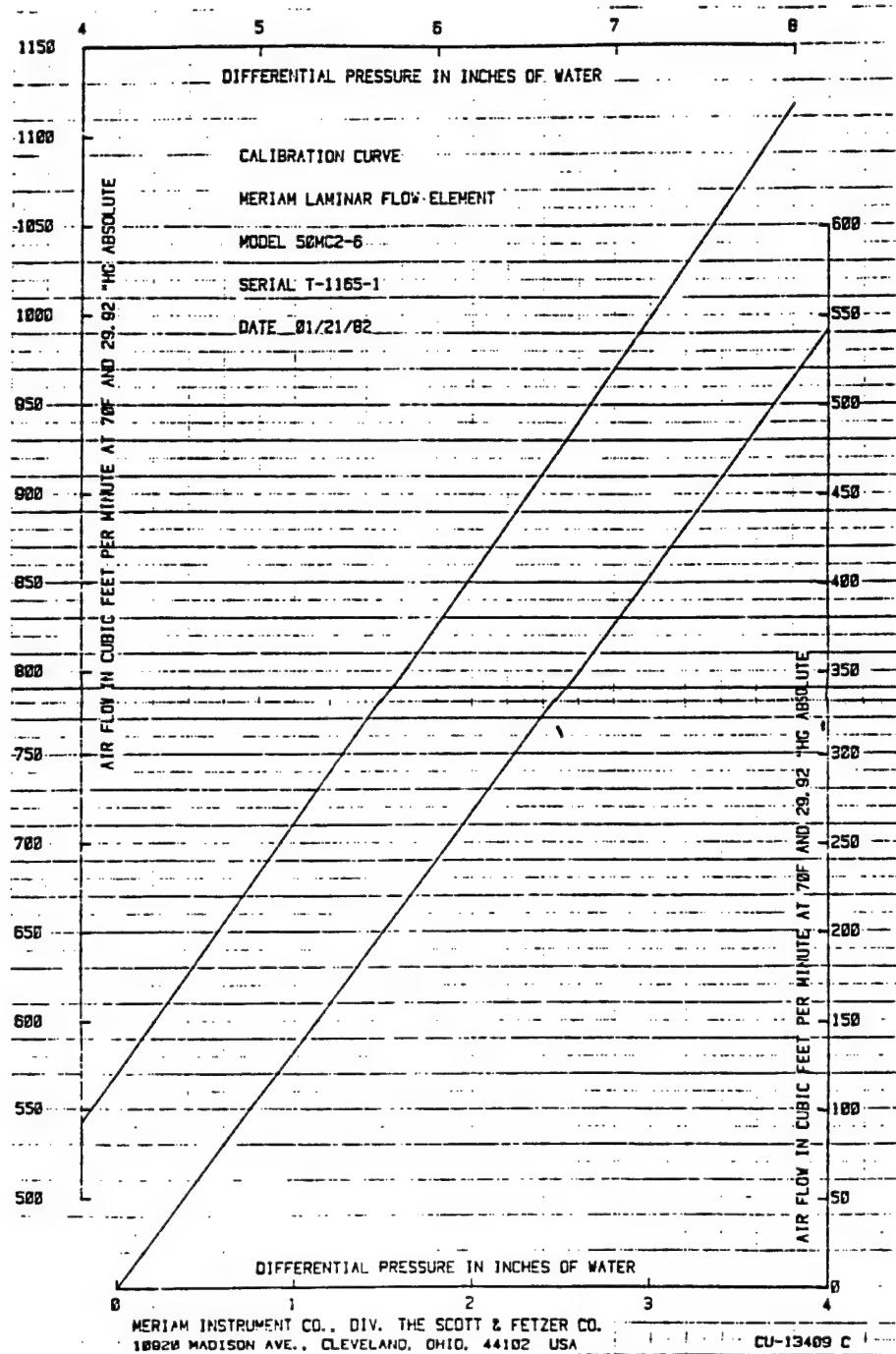


Figure B-2. Laminar Flow Element Calibration Sheet

## Appendix C

### Fire Test - Furnace Results

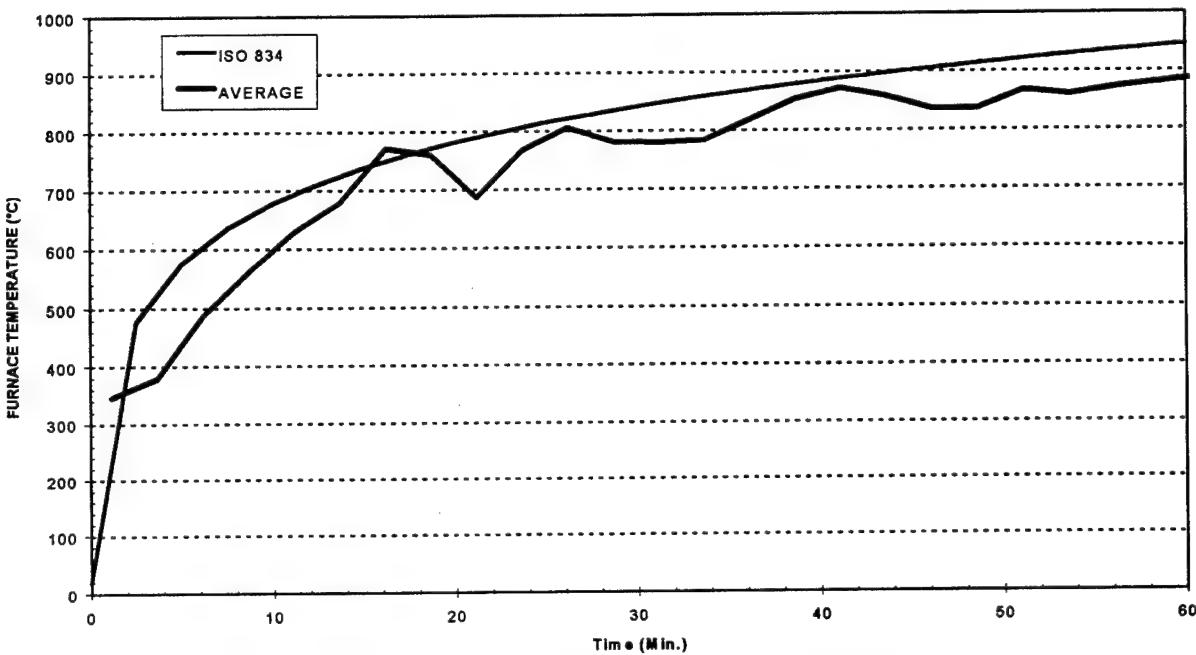


Figure C-1. Time-Temperature Curve for Bulkhead A

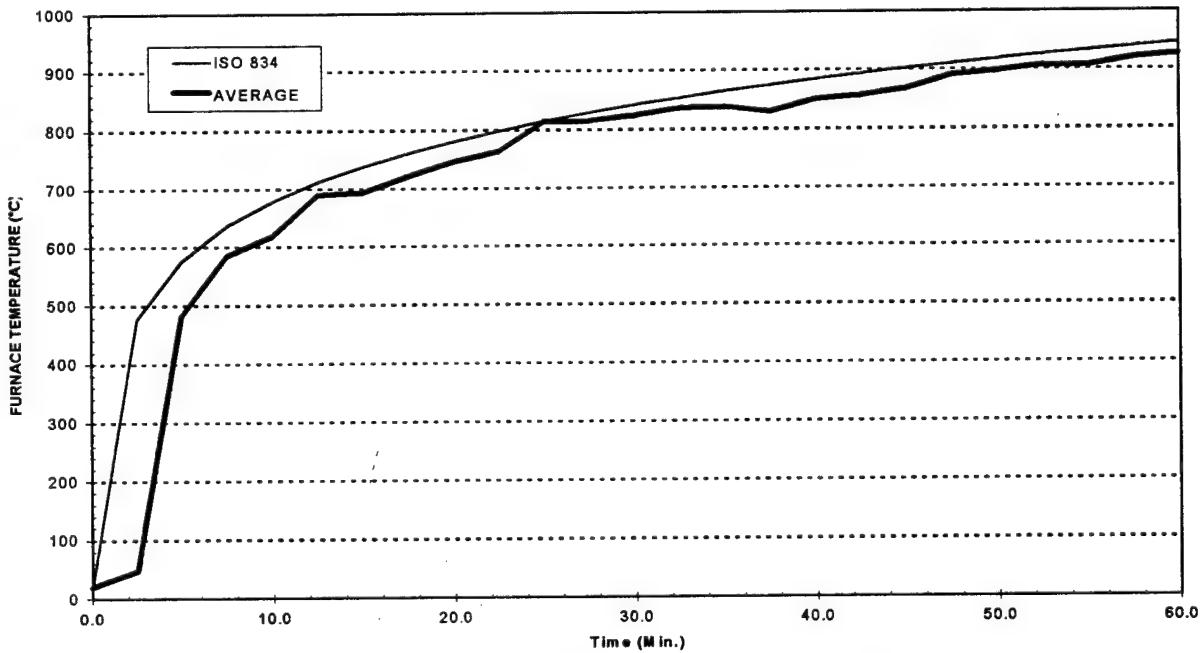


Figure C-2. Time-Temperature Curve for Bulkhead B

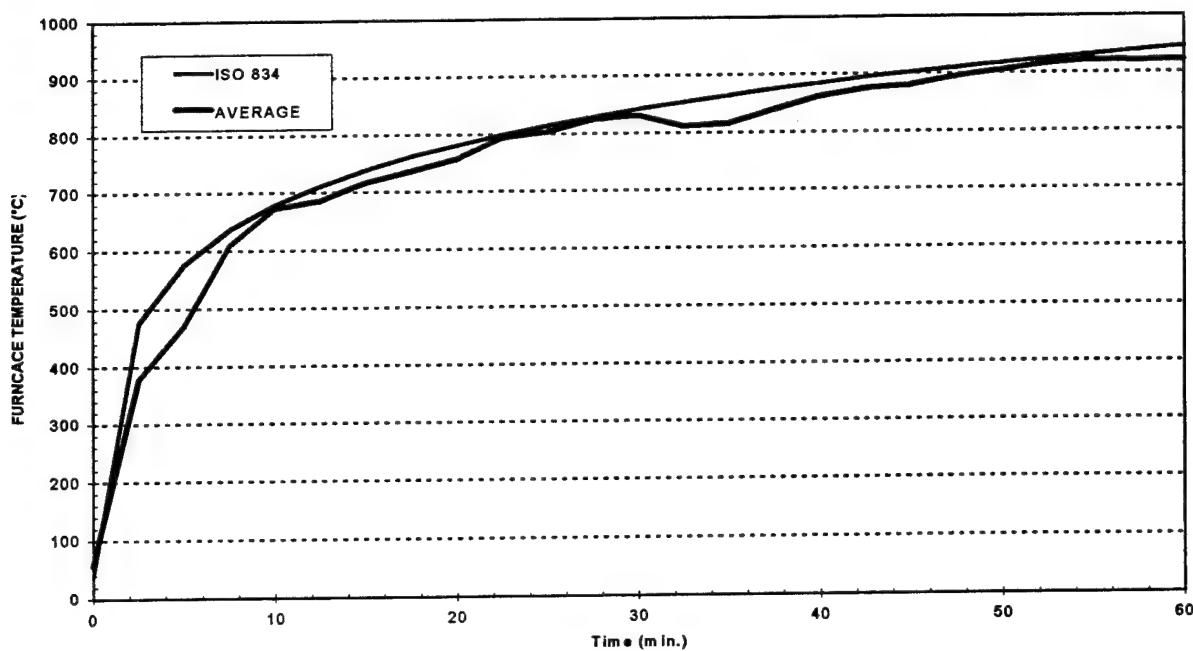


Figure C-3. Time-Temperature Curve for Bulkhead C

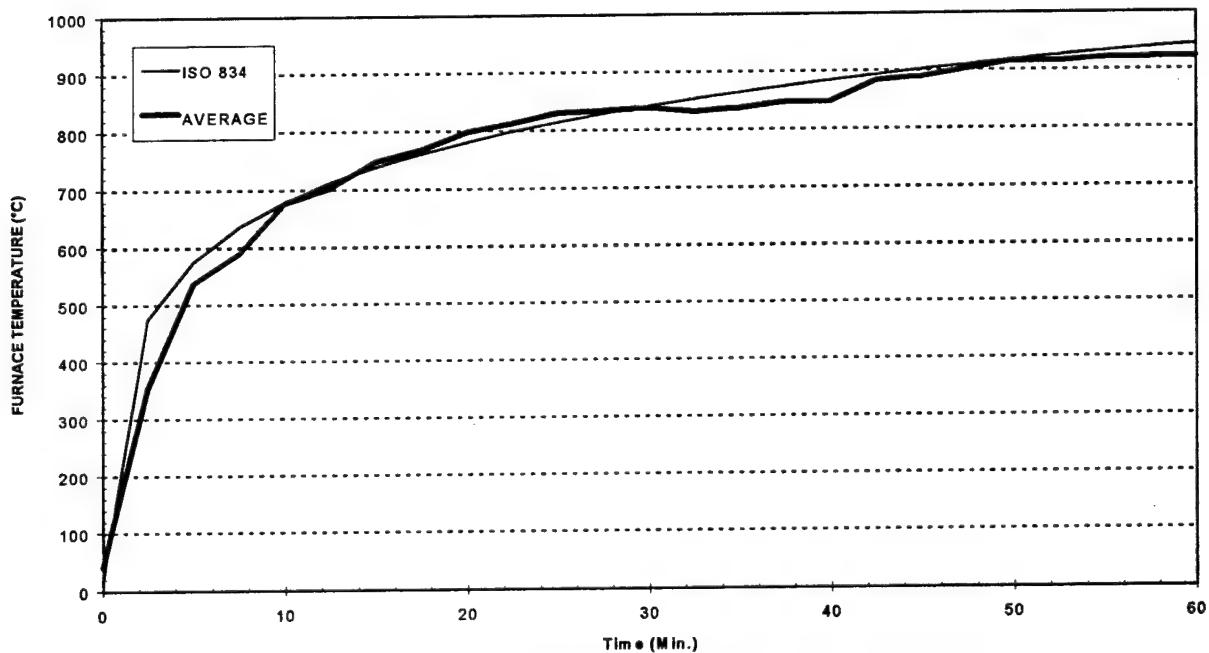


Figure C-4. Time-Temperature Curve for Bulkhead D

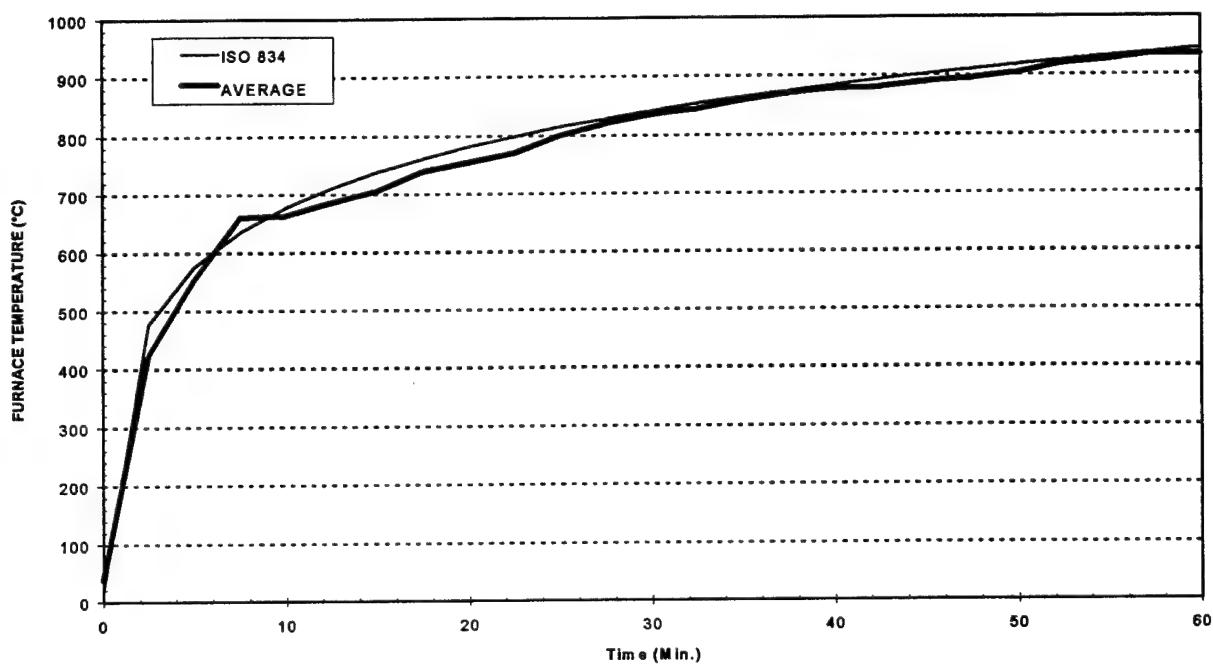


Figure C-5. Time-Temperature Curve for Bulkhead E

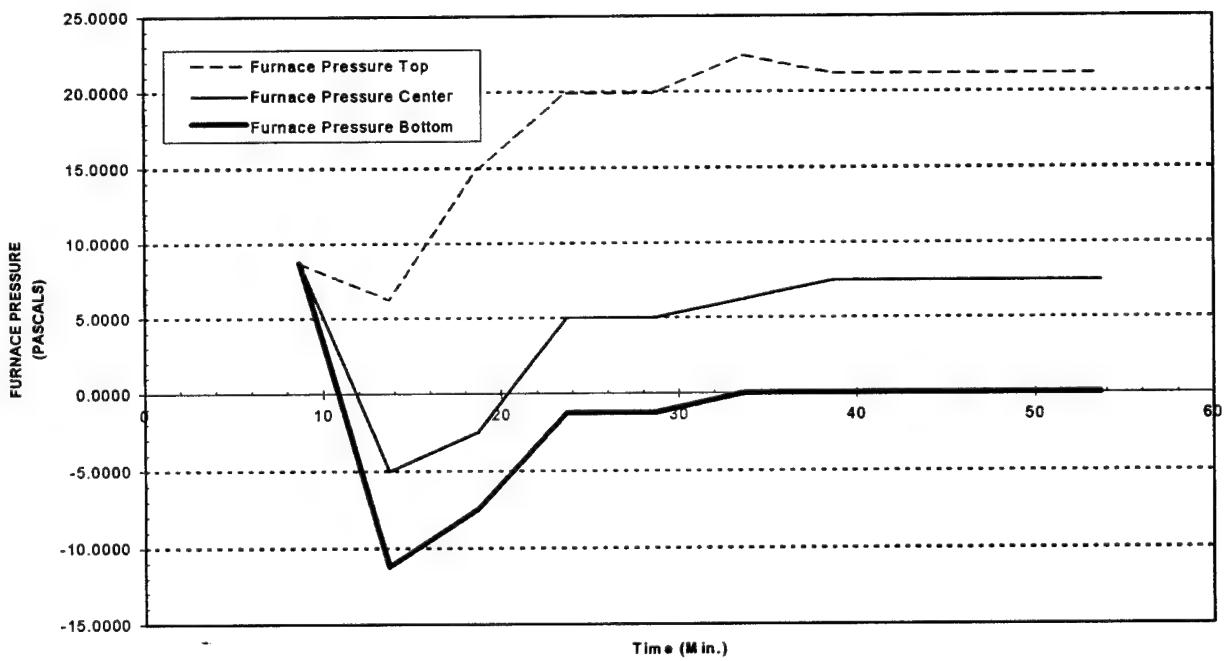


Figure C-6. Furnace Pressures for Bulkhead A

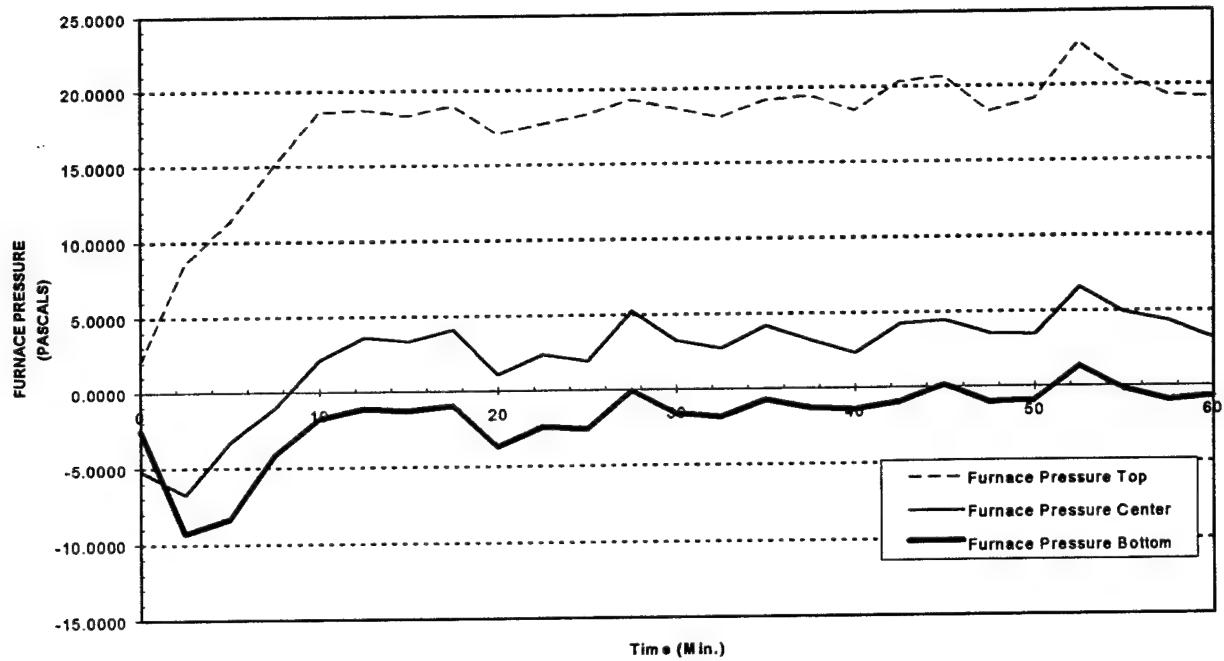


Figure C-7. Furnace Pressures for Bulkhead B

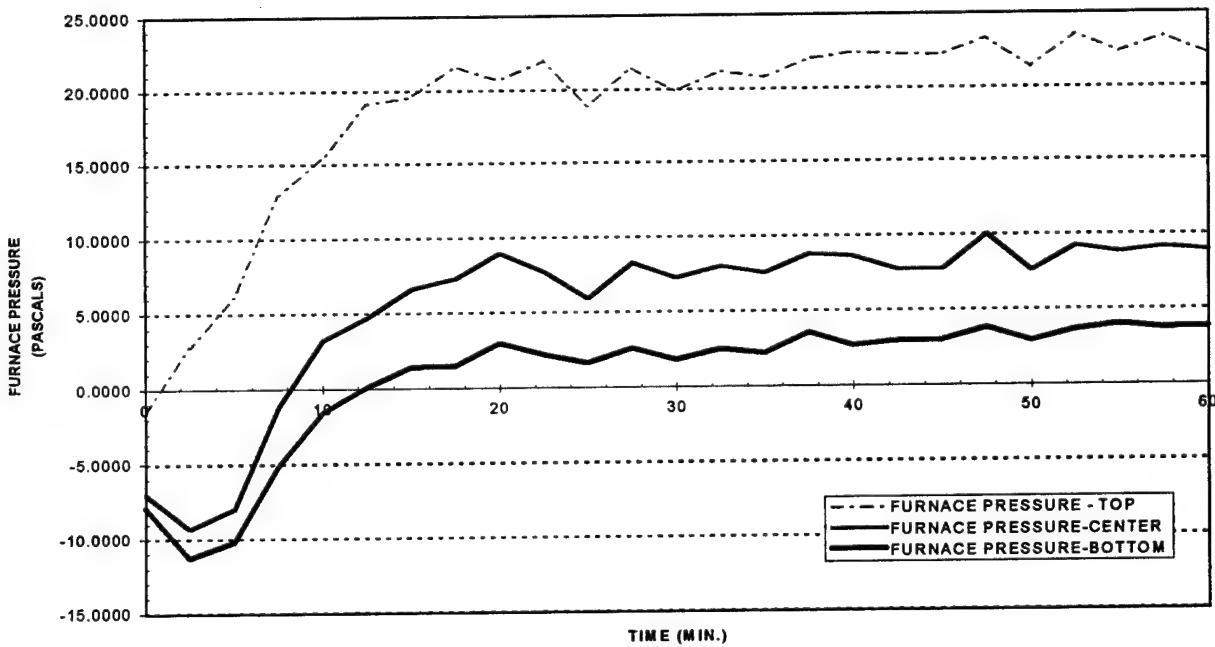


Figure C-8. Furnace Pressures for Bulkhead C

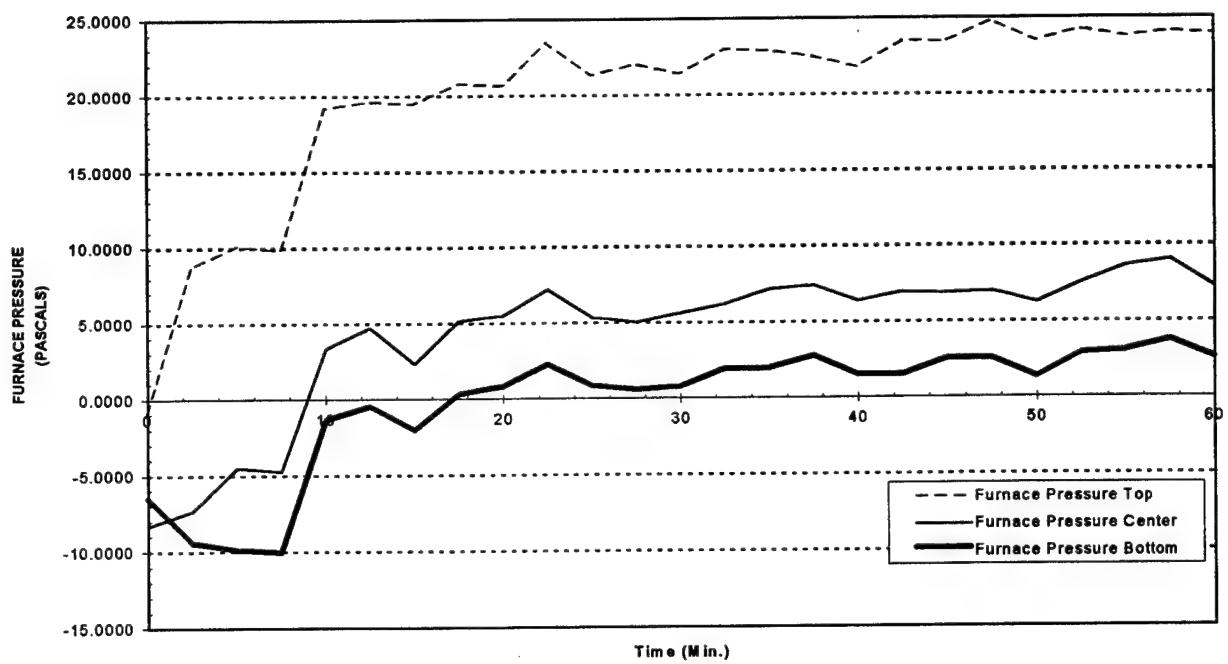


Figure C-9. Furnace Pressures for Bulkhead D

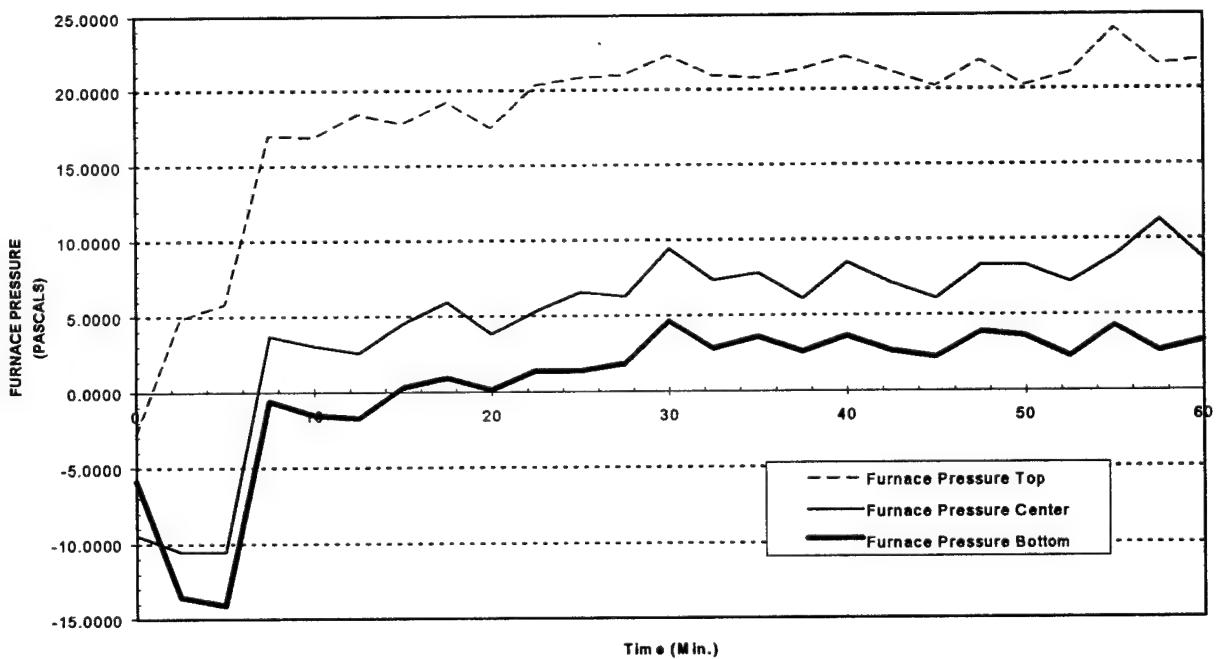


Figure C-10. Furnace Pressures for Bulkhead E

## Appendix D

### Fire Test - Unexposed Surface Temperatures

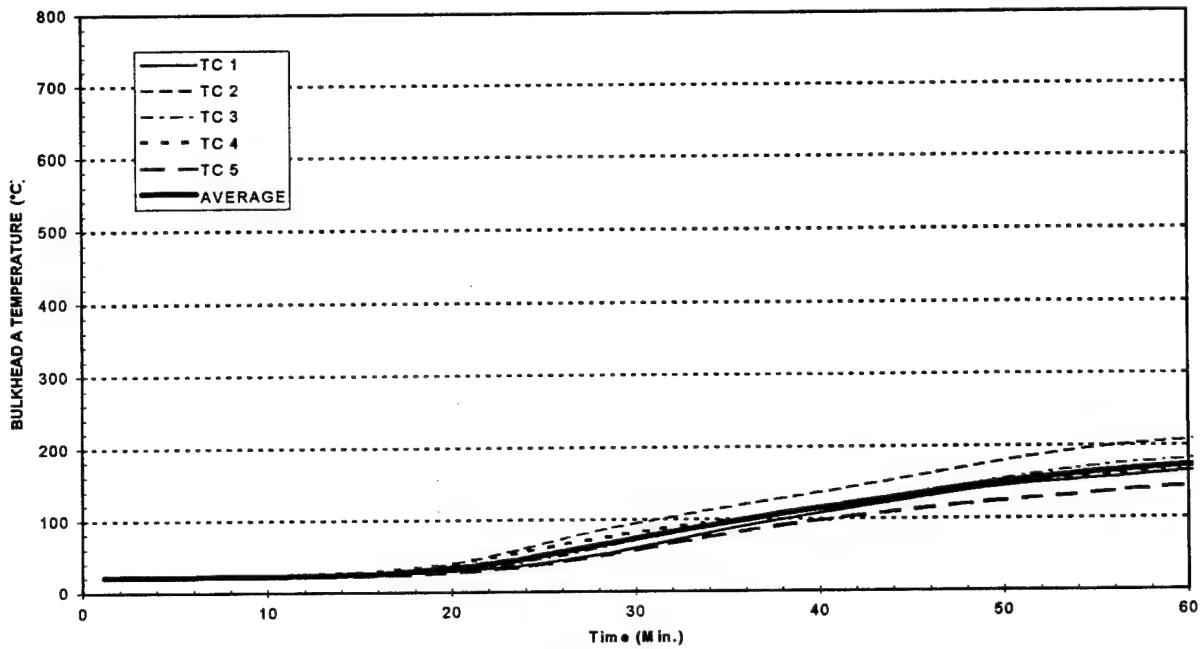


Figure D-1. Unexposed Surface Temperature: Bulkhead A

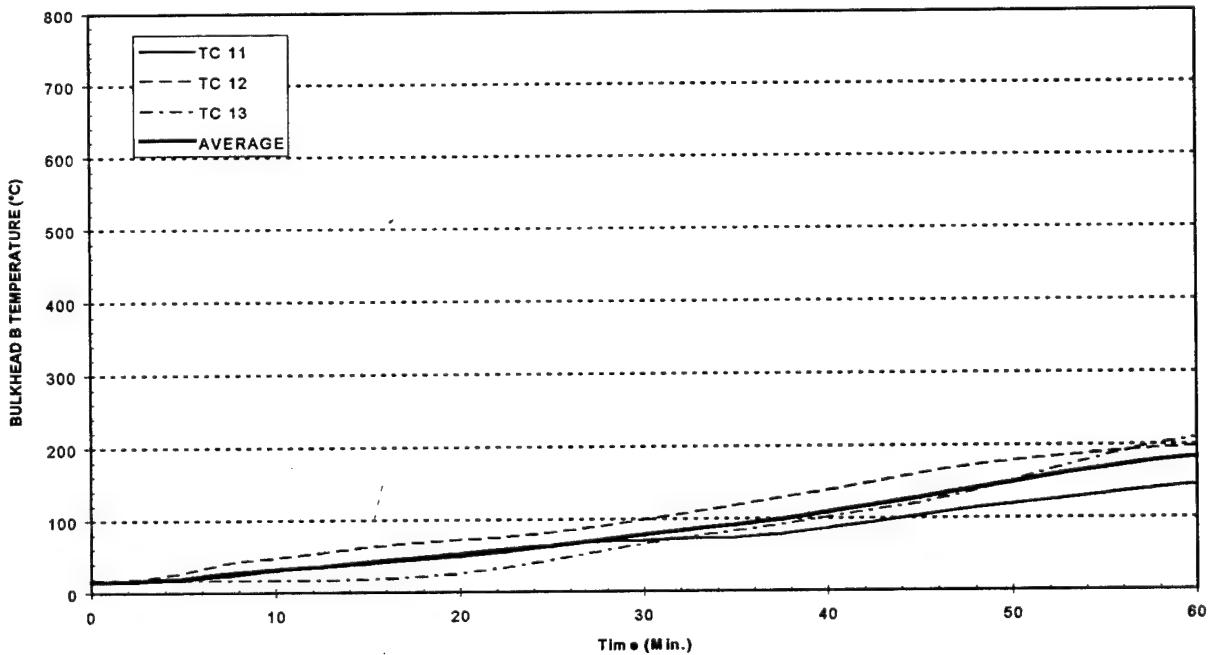


Figure D-2. Unexposed Surface Temperature: Bulkhead B

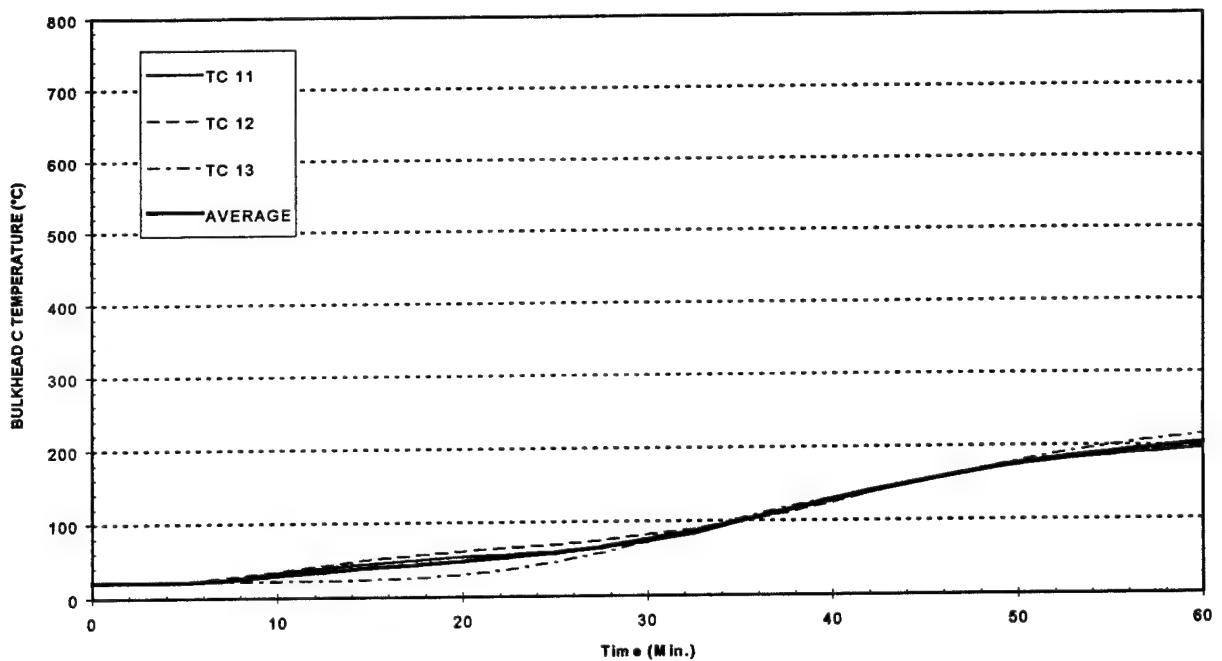


Figure D-3. Unexposed Surface Temperature: Bulkhead C

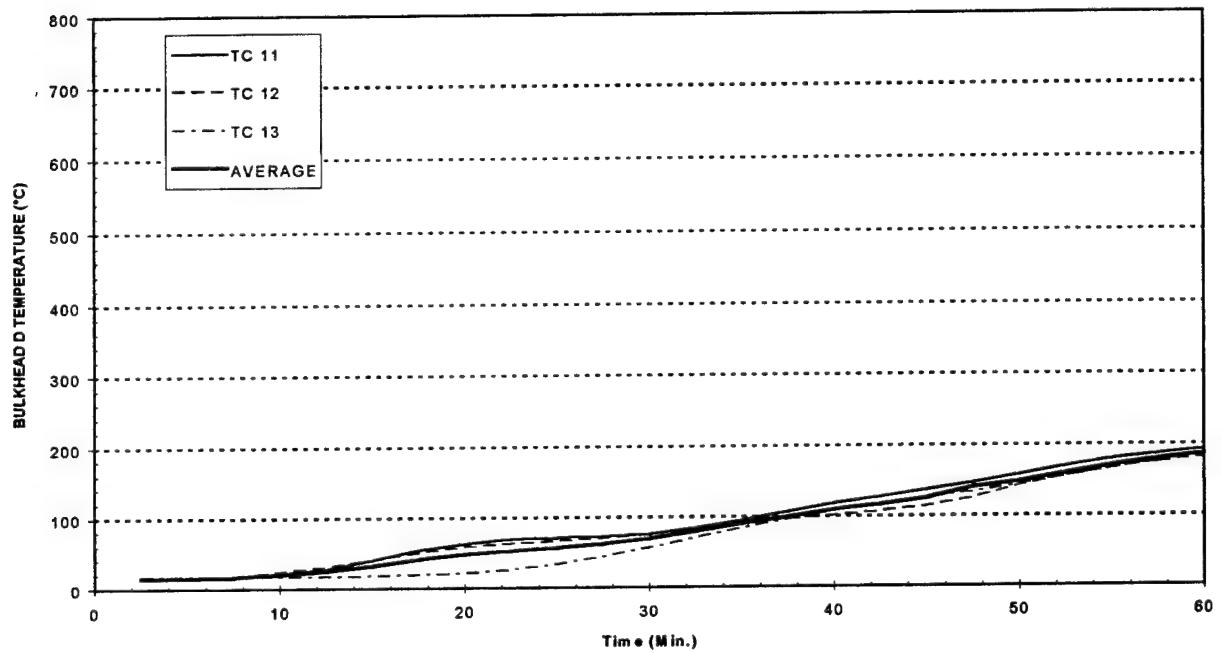


Figure D-4. Unexposed Surface Temperature: Bulkhead D

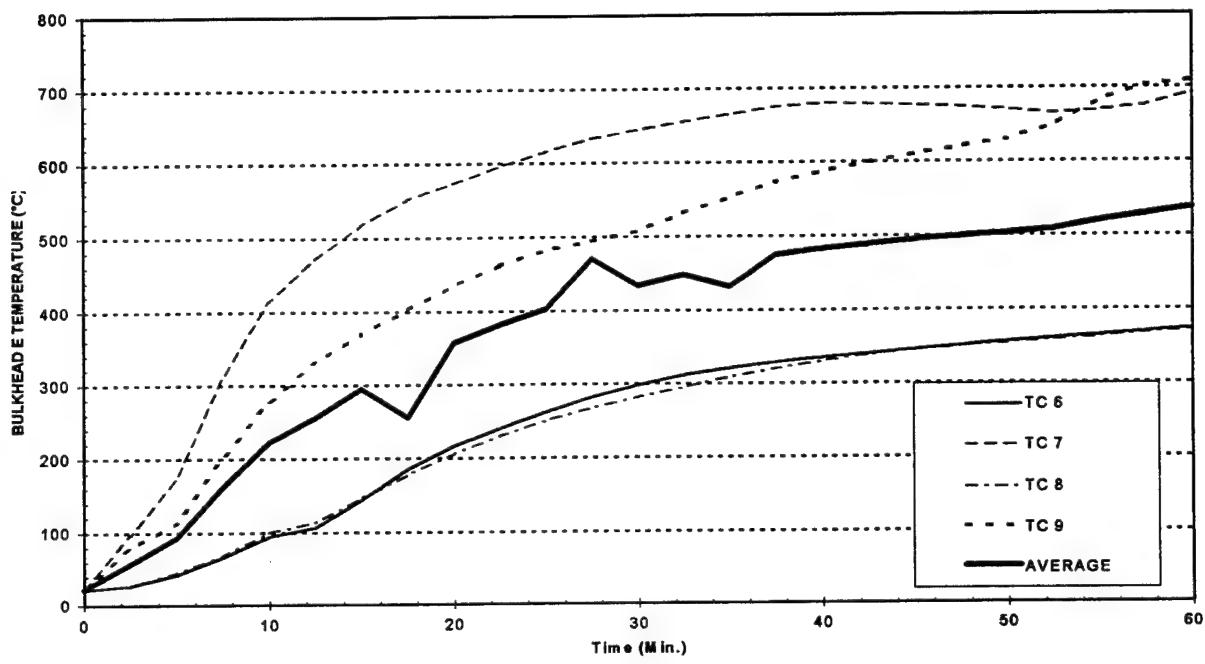


Figure D-5. Unexposed Surface Temperature: Bulkhead E

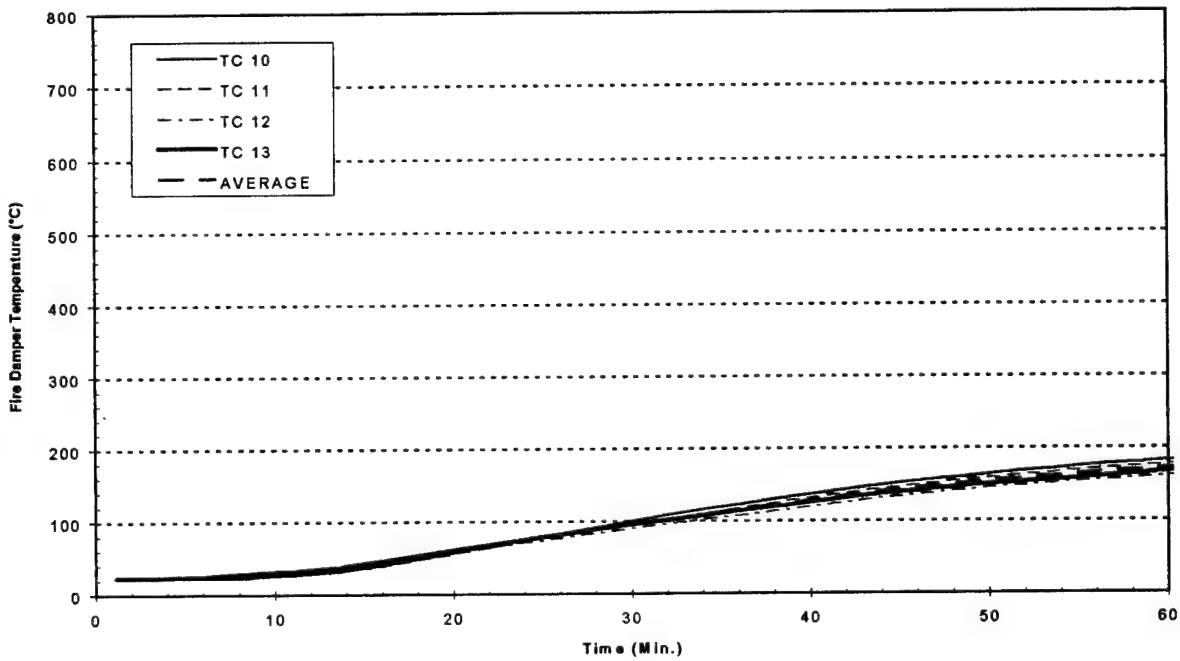


Figure D-6. Unexposed Surface Temperature: Fire Damper (Sample 1)

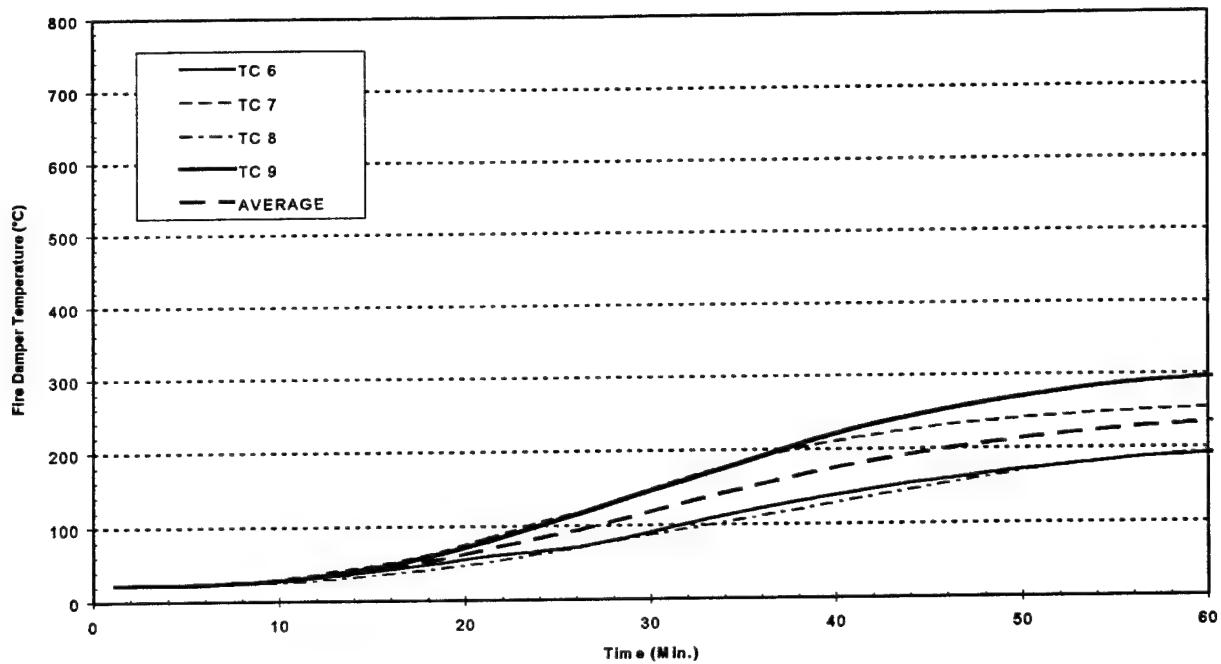


Figure D-7. Unexposed Surface Temperature: Fire Damper (Sample 2)

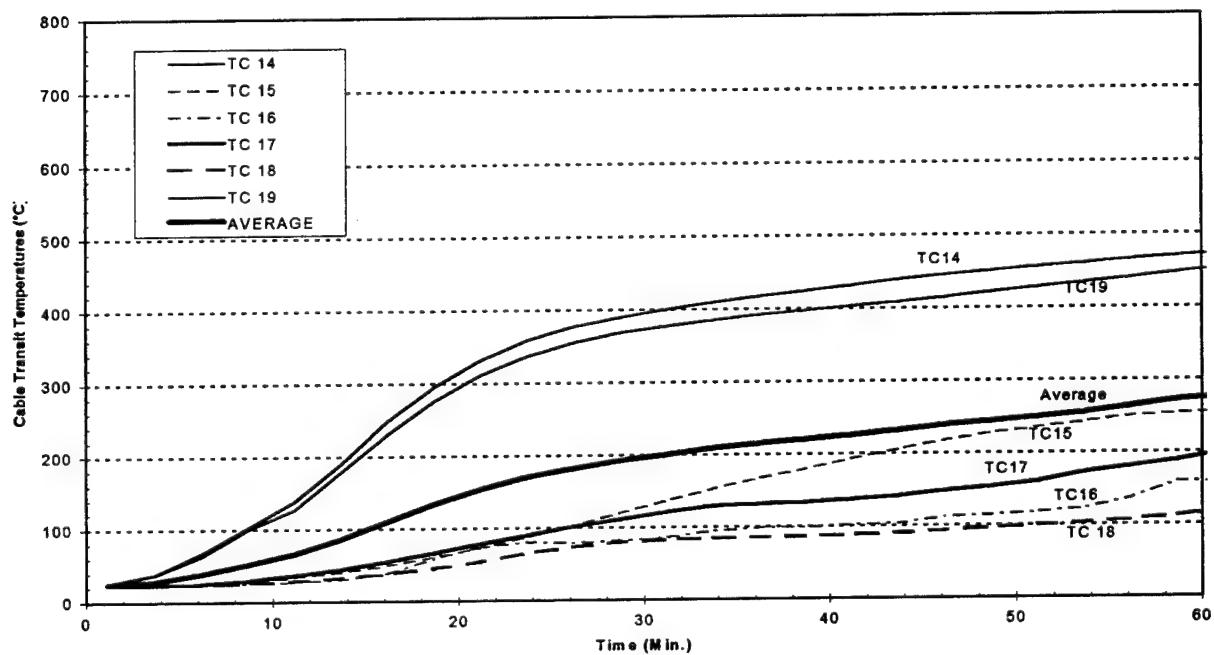


Figure D-8. Unexposed Surface Temperature: Fire Stop (Sample 3)

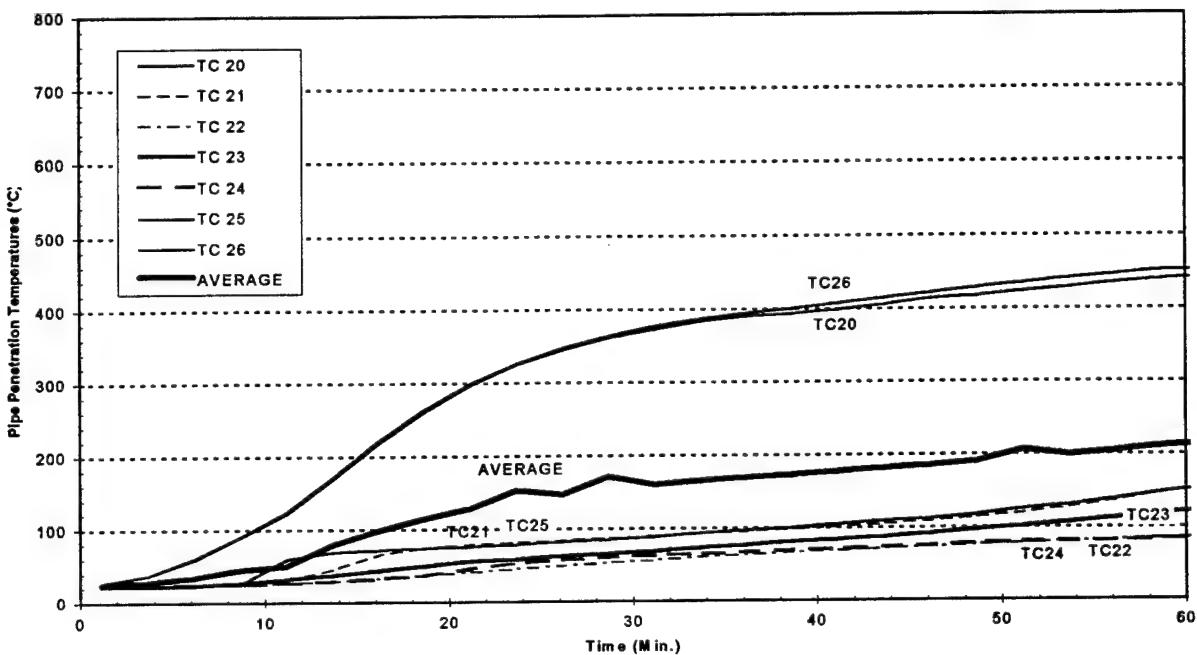


Figure D-9. Unexposed Surface Temperature: Fire Stop (Sample 4)

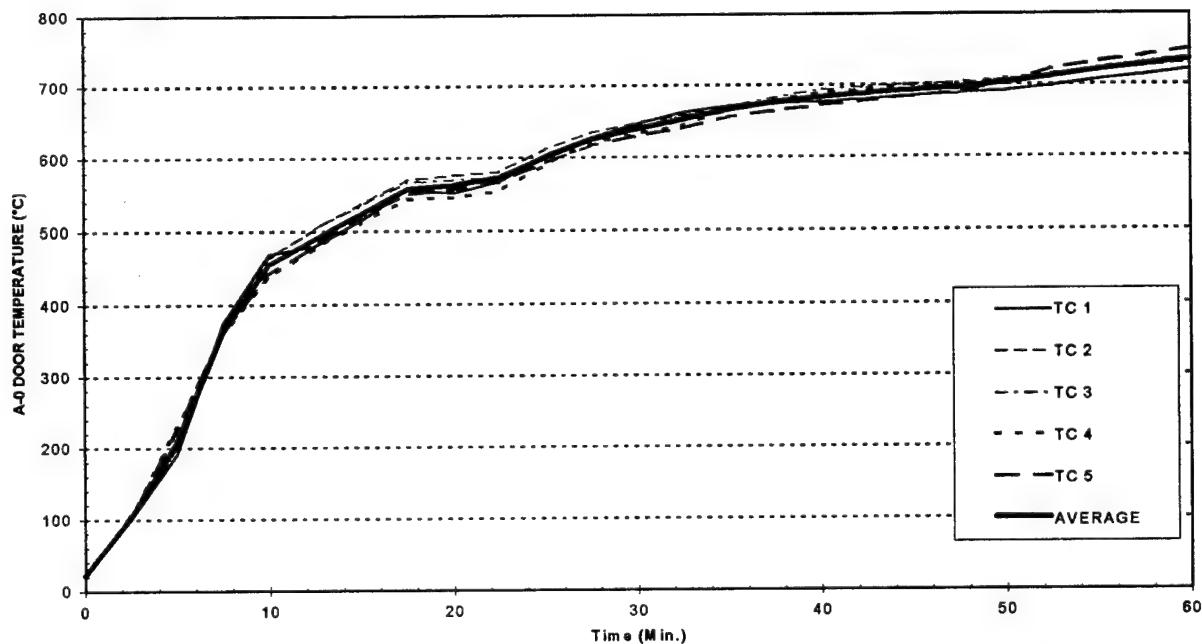


Figure D-10. Unexposed Surface Temperature: A-0 Fire Door (Sample 5)

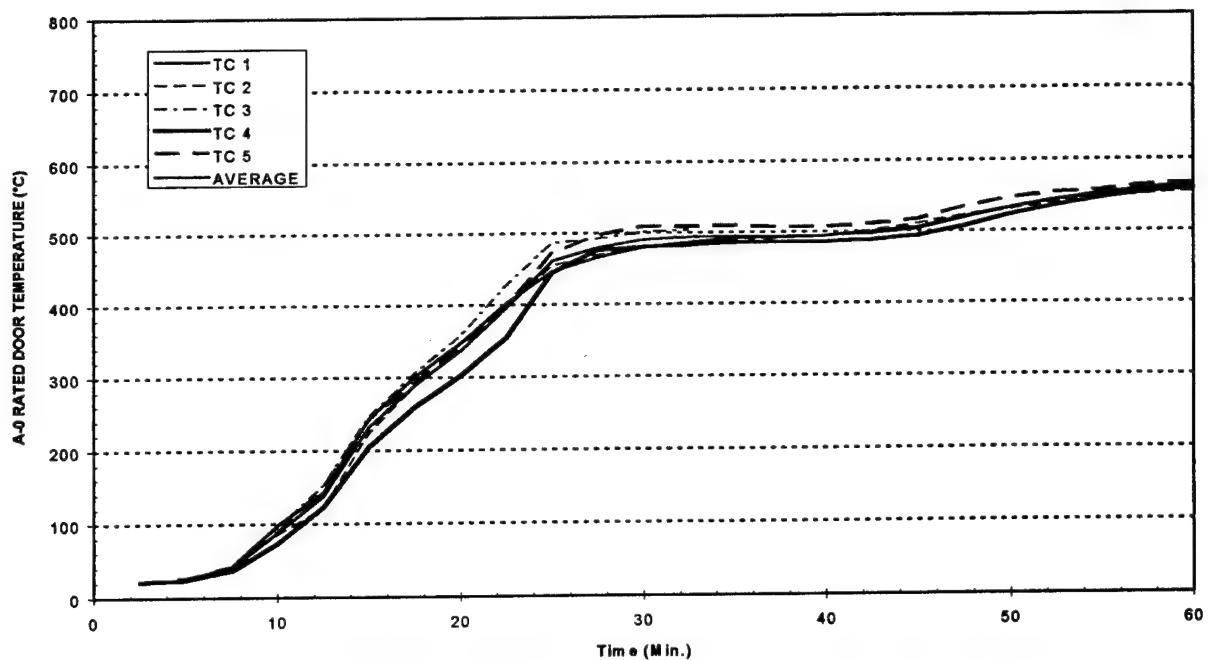


Figure D-11. Unexposed Surface Temperature: A-0 Fire Door (Sample 6)

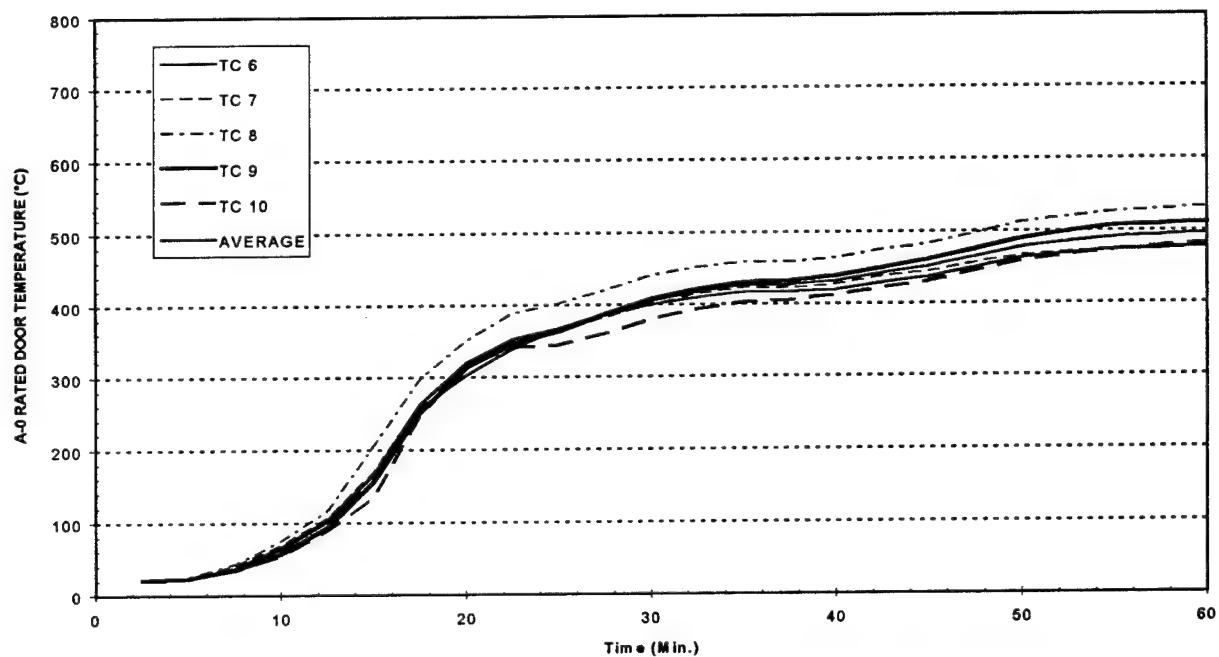


Figure D-12. Unexposed Surface Temperature: A-0 Fire Door (Sample 7)

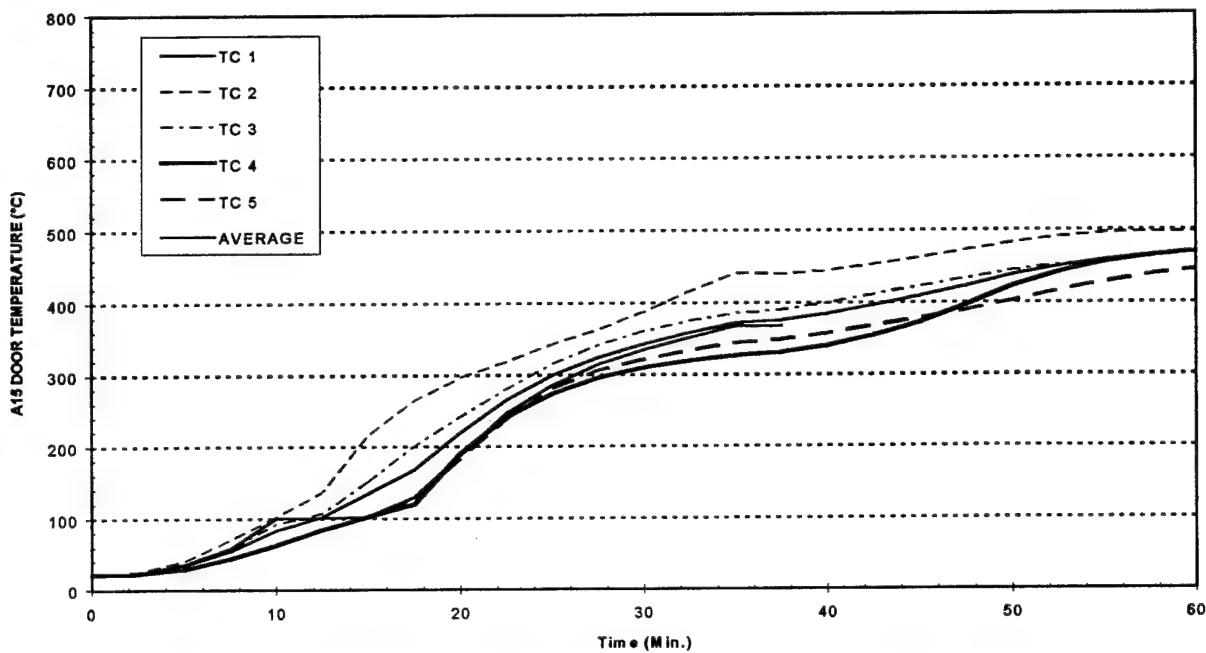


Figure D-13. Unexposed Surface Temperature: A-15 Fire Door (Sample 8)

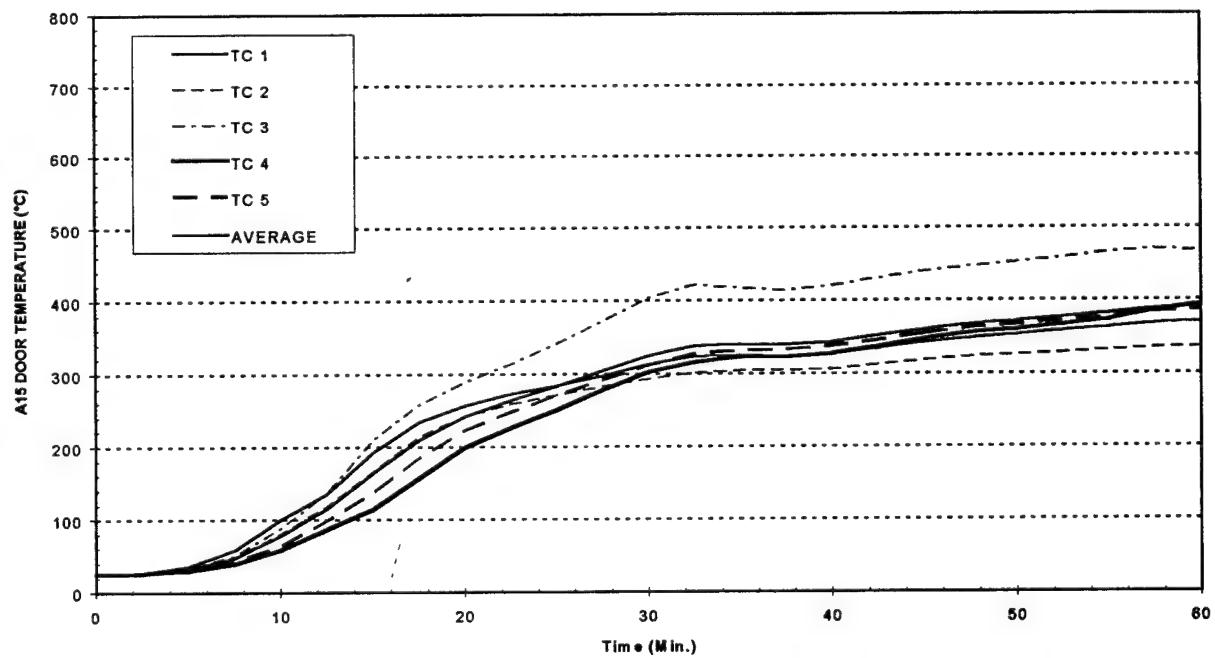


Figure D-14. Unexposed Surface Temperature: A-15 Fire Door (Sample 9)

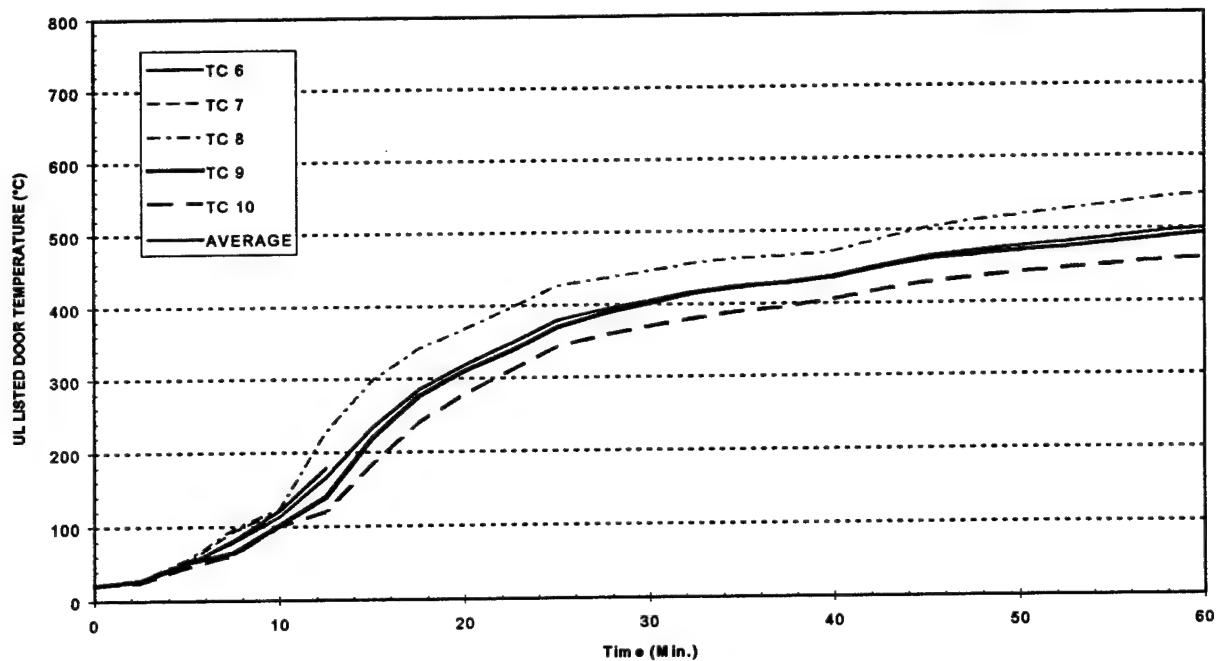


Figure D-15. Unexposed Surface Temperature : UL Listed 1-Hour Fire Door (Sample 10)

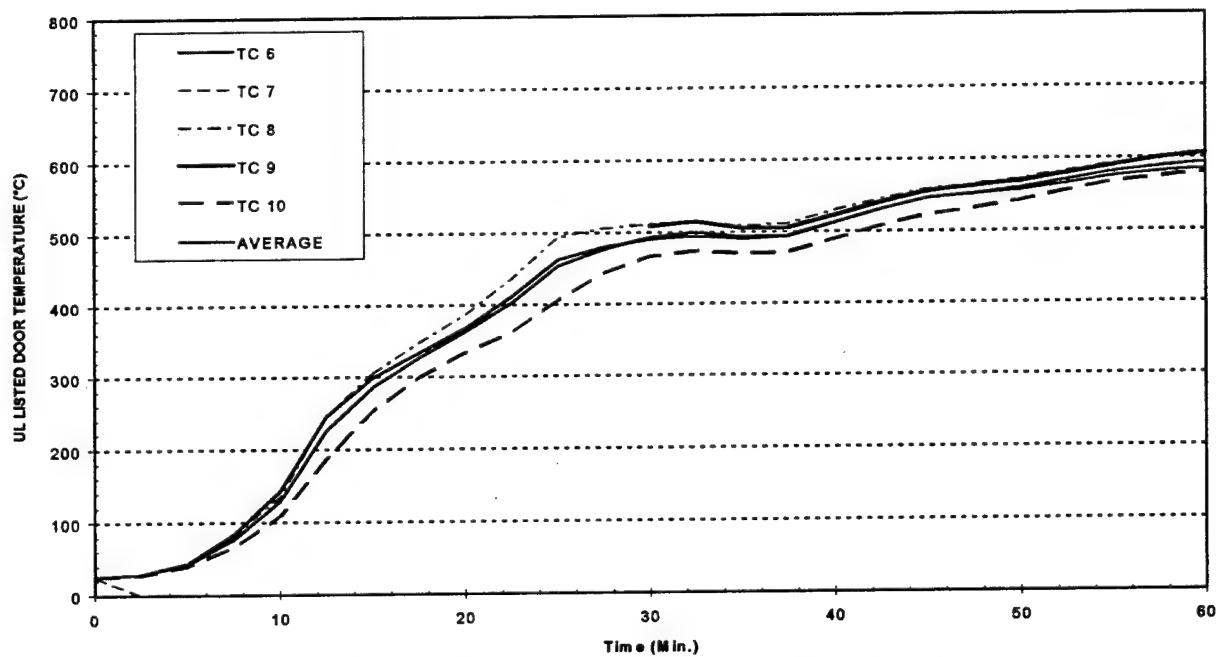


Figure D-16. Unexposed Surface Temperature : UL Listed 1-Hour Fire Door (Sample 11)

## Appendix E

### Fire Test Results - Observations and Deflections

#### Bulkhead A

#### Fire Stops and Dampers

##### Visual Observations 5/12/94:

| <u>Time min:sec</u> | <u>Observations</u>  |
|---------------------|--|
| 0:00                | Gas on.  |
| 2:30 exp. side      | The cable has ignited.   |
| 5:45                | The south damper has closed.   |
| 6:45                | Smoke is steadily emitting from the north duct.  |
| 6:58                | The north damper has closed.   |
| 8:00 exp. side      | The fire stop sealant is burning.  |
| 13:20               | A cotton pad test is conducted on the gases emitted from the cable transit. (negative)   |
| 14:00               | Steady smoke is being emitted from the cable transit and light intermittent smoke is being emitted from the pipe penetrations. |
| 16:00 exp. side     | The bulkhead face is deforming.  |
| 38:00               | A cotton pad test is conducted on the gases emitted from the pipe penetrations. (negative)                                     |
| 45:00               | A cotton pad test is conducted on the gases emitted from the cable transit. (negative)   |
| 55:00               | There is heavy smoke from the cable transits.  |
| 60:00               | Gas off. The fire stops are still burning on the exposed side. The flames are extinguished with a light application of water.  |

##### Deflection of Assembly Toward Furnace:

| <u>Time(min)</u> | <u>North</u> | <u>Center of Bulkhead</u> | <u>South</u> |
|------------------|--------------|---------------------------|--------------|
| Datum            | 254          | 254                       | 254          |
| 10               | 305          | 318                       | 311          |
| 20               | 298          | 324                       | 330          |
| 30               | 279          | 318                       | 330          |
| 40               | 267          | 318                       | 330          |

**Bulkhead B**

**A-15 South Door: UL Rated 1 Hour North Door**

**Visual Observations 5/17/94:**

| <u>Time min:sec</u> | <u>Observations</u>   |
|---------------------|---|
| 0:00                | Gas on.   |
| 3:30                | The spot welds are popping in both doors.   |
| 7:20                | The entire bulkhead is noticeably deflecting towards the furnace. Light smoke is being emitted from the tops of both doors.   |
| 9:30                | The top of the south door has a wavy deformation along the top.   |
| 10:00               | A cotton pad test is conducted on the gases from the south door top (negative). The door skins are discoloring outlining the stiffener pattern.                                   |
| 14:20               | T.C.'s #6 and 7 have disengaged from the sample.  |
| 34:00               | The south door latch edge top corner has deflected towards the furnace away from the frame stop approx. 20 min.   |
| 36:00               | A cotton pad test is conducted on the south door top edge where light licks of flames are noticed. (negative)   |
| 37:30               | T.C. #1 has disengaged from the sample.   |
| 60:00               | Gas off. The maximum separation of the north door top latch edge corner away from the frame stop is approx. 8 mm. All other locations are tight against the frame for both doors. |

**Deflection of Assembly Toward Furnace:**

| <u>Time (min)</u> | <u>North</u> | <u>South</u> |
|-------------------|--------------|--------------|
| Datum             | 286          | 292          |
| 5                 | 305          | 298          |
| 10                | 311          | 324          |
| 20                | 318          | 330          |
| 30                | 318          | 318          |
| 45                | 318          | 318          |

## Bulkhead C

### A-15 South Door: UL Rated 1 Hour North Door

#### Visual Observations 5/24/94:

| <u>Time min:sec</u> | <u>Observations</u>  |
|---------------------|--|
| 0:00                | Gas on.  |
| 1:00                | The spot welds are popping in both doors.  |
| 7:17                | Light smoke is being emitted from the tops of both doors.  |
| 15:00               | Light wisps of flame are noted from the top of the south door. A cotton pad test is conducted on the hot gases that are emitting. (negative) |
| 60:00               | Gas off. Both doors are tight up against the frame stops.  |

#### Deflection of Assembly Toward Furnace:

| <u>Time (min)</u> | <u>North</u> | <u>Center of Bulkhead</u> | <u>South</u> |
|-------------------|--------------|---------------------------|--------------|
| Datum             | 273          | 229                       | 267          |
| 10                | 305          | 279                       | 286          |
| 20                | 305          | 292                       | 305          |
| 30                | 292          | 279                       | 305          |
| 40                | 292          | 279                       | 286          |

## Bulkhead D

### A-0 Fire Doors

#### Visual Observations 6/2/94:

| <u>Time min:sec</u> | <u>Observations</u>  |
|---------------------|--|
| 0:00                | Gas on.  |
| 8:00                | Light smoke is being emitted from the tops of both doors.  |
| 13:00               | The door skins are beginning to discolor outlining the stiffener pattern.  |
| 30:00               | The upper hinge edge corner of the north door has separated approx. 10 mm from the frame stop towards furnace. A cotton pad test is conducted on the hot gases that are emitting. (negative) |
| 60:00               | Gas off. The south door remained tight up against the frame. No further movement of the north door.  |

#### Deflection of Assembly Toward Furnace:

| <u>Time (min)</u> | <u>North</u> | <u>Center of Bulkhead</u> | <u>South</u> |
|-------------------|--------------|---------------------------|--------------|
| Datum             | 286          | 235                       | 273          |
| 5                 | 305          | 254                       | 292          |
| 10                | 324          | 286                       | 318          |
| 20                | 318          | 298                       | 318          |
| 30                | 305          | 298                       | 305          |

Bulkhead E

A-0 Fire Door

Visual Observations 6/7/94:

| <u>Time min:sec</u> | <u>Observations</u>  |
|---------------------|--|
| 0:00                | Gas on.  |
| 23:00               | The upper latch edge corner has separated 1/2 in. from the frame stop towards the furnace. A cotton pad test is conducted on the hot gases. (negative)                                     |
| 35:00               | Steady flaming is noticed from the upper latch edge corner. The flaming is a result of furnace gas and air mixing through the door crack and combusting. The separation is approx. 3/4 in. |
| 50:30               | Both the latch edge corners have separated 3/4 in. towards the furnace.  |
| 60:00               | Gas off. The door is unlatched but has not swung open or separated from the frame any further.   |

Deflection of Assembly Toward Furnace:

| <u>Time (min)</u> | <u>North</u> | <u>Center of Bulkhead</u> | <u>South</u> |
|-------------------|--------------|---------------------------|--------------|
| Datum             | 339          | 330                       | 311          |
| 5                 | 394          | 362                       | 343          |
| 10                | 906          | 381                       | 356          |
| 20                | 419          | 394                       | 368          |

## Appendix F

### Leakage Test Data

Table F-1. Environment During Leakage Tests

| Bulkhead | Pre Fire Test Environment |                                |                             |   | Post Fire Test Environment |                                |                             |   |
|----------|---------------------------|--------------------------------|-----------------------------|---|----------------------------|--------------------------------|-----------------------------|---|
|          | Temperature<br>(°C)       | Barometric<br>Pressure<br>(Pa) | Relative<br>Humidity<br>(%) | Saturated<br>Vapor<br>Pressure<br>[vii]<br>(Pa) | Temperature<br>(°C)        | Barometric<br>Pressure<br>(Pa) | Relative<br>Humidity<br>(%) | Saturated<br>Vapor<br>Pressure[vii]<br>(Pa) |
| A        | 22.4                      | 99395                          | 33                          | 2828  | 17.7                       | 99302                          | 42                          | 2095  |
| B        | 17.7                      | 99954                          | 40                          | 2095  | 20.0                       | 99848                          | 29                          | 2453  |
| C        | 21.6                      | 98980                          | 59                          | 2703  | 21.1                       | 98102                          | 56                          | 2625  |
| D        | 22.2                      | 99419                          | 40                          | 2796  | 20.8                       | 99723                          | 52                          | 2578  |
| E        | 23.3                      | 98710                          | 54                          | 2968  | 18.3                       | 99216                          | 60                          | 2188  |

Table F-2. Pre Fire Test - Uncorrected Leakage Test Results

| Test       | Leakage Rate (m <sup>3</sup> /hr) |        |        |        |        |        |         |       |                           |
|------------|-----------------------------------|--------|--------|--------|--------|--------|---------|-------|---------------------------|
|            | @5 Pa                             | @10 Pa | @20 Pa | @30 Pa | @50 Pa | @70 Pa | @100 Pa | @5 Pa | @ Highest Static Pressure |
| Bulkhead A | 6.9                               | 8.6    | 10.6   | 12.4   | 15.1   | 17.9   | 23.9    | 3.7   | 22.3                      |
| Sample 1   | 36.5                              | 43.8   | 60.6   | 75.2   | 75.6   | 93.5   | 116.0   | 18.8  | 117.3                     |
| Sample 2   | 30.9                              | 46.4   | 67.0   | 85.9   | 98.0   | 121.3  | 148.9   | 60.0  | 150.9                     |
| Sample 3   | 5.4                               | 7.3    | 10.0   | 12.6   | 17.1   | 21.6   | 27.9    | 6.2   | 28.1                      |
| Sample 4   | 1.1                               | 4.5    | 7.7    | 10.6   | 15.5   | 20.1   | 23.5    | 4.9   | 29.5                      |
| Bulkhead A | 6.6                               | 8.4    | 11.3   | 14.0   | 18.8   | 23.6   | 30.1    | 6.9   | 29.7                      |
| Bulkhead B | 39.3                              | 47.5   | 60.7   | 70.4   | 86.9   | 74.5   | 88.4    | 27.6  | 87.6                      |
| Sample 8   | 375.3                             | 419.8  | 499.1  | 615.9  | 689.0  | 790.7  | 922.9   | 386.4 | 928.2                     |
| Sample 10  | OROR                              | 368.7  | 470.7  | 565.4  | 706.6  | 774.3  | 928.2   | 217.6 | 934.1                     |
| Bulkhead B | 27.4                              | 31.3   | 38.0   | 45.1   | 57.0   | 65.3   | 78.5    | 25.6  | 76.9                      |
| Bulkhead C | 29.5                              | 32.0   | 34.4   | 42.6   | 50.4   | 58.6   | 93.0    | OROR  | 93.0                      |
| Sample 9   | 358.8                             | 382.5  | 457.1  | 522.5  | 642.0  | 741.2  | 872.6   | 363.7 | 871.6                     |
| Sample 11  | 373.8                             | 427.1  | 500.7  | 571.9  | 694.4  | 812.5  | 939.9   | 389.8 | 941.8                     |
| Bulkhead C | 24.2                              | 26.2   | 29.1   | 31.5   | 38.3   | 42.1   | 49.4    | 22.8  | 50.0                      |
| Bulkhead D | 14.5                              | 19.4   | 26.6   | 31.5   | 42.6   | 50.4   | 61.0    | 17.9  | 59.6                      |
| Sample 6   | 351.5                             | 387.9  | 467.8  | 522.0  | 640.6  | 751.0  | 876.4   | 357.8 | 878.4                     |
| Sample 7   | 351.5                             | 406.3  | 495.4  | 559.3  | 701.6  | 827.5  | 967.5   | 372.9 | 970.9                     |
| Bulkhead D | 25.2                              | 31.5   | 43.1   | 50.4   | 59.6   | 70.2   | 78.0    | 29.5  | 78.9                      |
| Bulkhead E | 24.7                              | 28.6   | 31.5   | 35.8   | 43.6   | 49.9   | 58.1    | 27.1  | 58.6                      |
| Sample 5   | 611.1                             | 648.4  | 717.1  | 787.8  | 900.6  | 1018.3 | 1153.9  | 617.4 | 1154.9                    |
| Bulkhead E | 29.1                              | 30.5   | 34.4   | 39.2   | 46.0   | 52.8   | 62.5    | OROR  | OROR                      |

Table F-3. Post Fire Test - Uncorrected Leakage Test Results

| Test       | Leakage Rate (m <sup>3</sup> /hr) |        |        |        |        |        |         |        |                           |
|------------|-----------------------------------|--------|--------|--------|--------|--------|---------|--------|---------------------------|
|            | @5 Pa                             | @10 Pa | @20 Pa | @30 Pa | @50 Pa | @70 Pa | @100 Pa | @5 Pa  | @ Highest Static Pressure |
| Bulkhead A | 70.9                              | 89.4   | 107.2  | 129.0  | 166.8  | 203.4  | 243.3   | 76.0   | 251.4                     |
| Sample 1   | 157.0                             | 166.5  | 195.9  | 219.5  | 265.5  | 305.0  | 354.6   | 162.6  | 363.1                     |
| Sample 2   | 176.2                             | 190.9  | 225.8  | 253.9  | 304.3  | 350.3  | 414.9   | 161.0  | 417.7                     |
| Sample 3   | 178.5                             | 198.3  | 233.5  | 267.1  | 318.9  | 367.8  | 425.7   | 163.0  | 427.5                     |
| Sample 4   | 106.1                             | 122.1  | 151.6  | 177.2  | 221.5  | 261.1  | 307.7   | 113.8  | 307.5                     |
| Bulkhead A | 119.1                             | 129.2  | 152.7  | 170.1  | 202.5  | 235.7  | 274.7   | 119.5  | 274.8                     |
| Bulkhead B | 32.3                              | 60.6   | 75.1   | 92.2   | 119.4  | 143.4  | 174.1   | 59.6   | 177.0                     |
| Sample 8   | 916.1                             | 975.2  | 1097.1 | 1188.3 | 1411.1 | 1560.1 | OR      | 907.5  | 1557.2                    |
| Sample 10  | 1036.0                            | 1124.0 | 1240.7 | 1388.2 | 1597.9 | OR     | OR      | 1081.7 | 1605.2                    |
| Bulkhead B | 67.5                              | 76.6   | 88.6   | 101.7  | 124.0  | 143.8  | 168.8   | 70.2   | 170.4                     |
| Bulkhead C | 98.3                              | 137.6  | 183.5  | 217.4  | 290.2  | 355.4  | 443.1   | 160.3  | 450.8                     |
| Sample 9   | 834.3                             | 896.3  | 1018.3 | 1126.5 | 1334.5 | OR     | OR      | 861.9  | 1335.0                    |
| Sample 11  | 757.6                             | 845.0  | 1021.7 | 1138.4 | 1404.7 | OR     | OR      | 797.5  | 1418.8                    |
| Bulkhead C | 215.5                             | 240.2  | 276.1  | 303.6  | 356.6  | 414.0  | 486.2   | 215.0  | 483.7                     |
| Bulkhead D | 46.0                              | 71.2   | 106.0  | 130.7  | 172.9  | 216.0  | 262.9   | 79.4   | 262.5                     |
| Sample 6   | 411.6                             | 596.1  | 801.4  | 982.5  | 1245.9 | 1539.3 | OR      | 600.4  | 1525.3                    |
| Sample 7   | 588.8                             | 715.2  | 951.5  | 1091.9 | 1387.3 | OR     | OR      | 676.9  | 1414.9                    |
| Bulkhead D | 104.1                             | 116.2  | 147.7  | 167.5  | 200.5  | 242.1  | 298.3   | 112.8  | 302.6                     |
| Bulkhead E | 25.7                              | 41.2   | 64.9   | 81.8   | 110.9  | 133.6  | 165.1   | 45.0   | 168.5                     |
| Sample 5   | 1114.2                            | 1220.2 | 1515.6 | OR     | OR     | OR     | OR      | OR     | OR                        |
| Bulkhead E | 75.5                              | 78.9   | 142.8  | OR     | OR     | OR     | OR      | 75.0   | OR                        |

OR - Over the range of the leakage equipment

Table F-4. Pre Fire Test - Corrected Leakage Test Results

|            | Leakage Rate (m <sup>3</sup> /hr) |        |        |        |        |        |         |       |                           |
|------------|-----------------------------------|--------|--------|--------|--------|--------|---------|-------|---------------------------|
|            | @5 Pa                             | @10 Pa | @20 Pa | @30 Pa | @50 Pa | @70 Pa | @100 Pa | @5 Pa | @ Highest Static Pressure |
| Bulkhead A | 6.7                               | 8.3    | 10.3   | 12.0   | 14.6   | 17.4   | 23.2    | 3.6   | 21.6                      |
| Sample 1   | 35.4                              | 42.5   | 58.8   | 72.9   | 73.3   | 90.7   | 112.6   | 18.2  | 113.8                     |
| Sample 2   | 30.0                              | 45.0   | 65.0   | 83.3   | 95.1   | 117.7  | 144.5   | 58.2  | 146.4                     |
| Sample 3   | 5.2                               | 7.1    | 9.7    | 12.2   | 16.6   | 21.0   | 27.1    | 6.0   | 27.3                      |
| Sample 4   | 1.1                               | 4.4    | 7.5    | 10.3   | 15.0   | 19.5   | 22.8    | 4.8   | 28.6                      |
| Bulkhead A | 6.4                               | 8.1    | 11.0   | 13.6   | 18.2   | 22.9   | 29.2    | 6.7   | 28.8                      |
| Bulkhead B | 39.0                              | 47.1   | 60.2   | 69.8   | 86.2   | 73.9   | 87.7    | 27.4  | 86.9                      |
| Sample 8   | 372.0                             | 416.1  | 494.8  | 610.6  | 683.2  | 784.2  | 915.6   | 383.0 | 920.9                     |
| Sample 10  |                                   | 365.5  | 466.6  | 560.5  | 700.7  | 768.0  | 920.9   | 215.7 | 926.7                     |
| Bulkhead B | 27.2                              | 31.0   | 37.7   | 44.7   | 56.5   | 64.8   | 77.9    | 25.4  | 76.3                      |
| Bulkhead C | 28.5                              | 30.9   | 33.2   | 41.1   | 48.7   | 56.6   | 89.9    |       | 89.9                      |
| Sample 9   | 346.5                             | 369.4  | 441.5  | 504.7  | 620.2  | 716.2  | 843.5   | 351.2 | 842.5                     |
| Sample 11  | 361.0                             | 412.5  | 483.6  | 552.4  | 670.9  | 785.1  | 908.5   | 376.4 | 910.3                     |
| Bulkhead C | 23.4                              | 25.3   | 28.1   | 30.4   | 37.0   | 40.7   | 47.7    | 22.0  | 48.3                      |
| Bulkhead D | 14.1                              | 18.8   | 25.8   | 30.6   | 41.3   | 48.9   | 59.2    | 17.4  | 57.9                      |
| Sample 6   | 340.9                             | 376.2  | 453.7  | 506.3  | 621.5  | 728.8  | 850.7   | 347.0 | 852.7                     |
| Sample 7   | 340.9                             | 394.0  | 480.5  | 542.5  | 680.7  | 803.0  | 939.2   | 361.6 | 942.5                     |
| Bulkhead D | 24.4                              | 30.5   | 41.8   | 48.9   | 57.8   | 68.1   | 75.7    | 28.6  | 76.6                      |
| Bulkhead E | 23.6                              | 27.4   | 30.2   | 34.3   | 41.8   | 47.8   | 55.7    | 25.9  | 56.2                      |
| Sample 5   | 585.1                             | 620.8  | 686.7  | 754.5  | 862.7  | 975.6  | 1105.9  | 591.1 | 1106.8                    |
| Bulkhead E | 27.9                              | 29.2   | 32.9   | 37.5   | 44.1   | 50.6   | 59.9    |       |                           |

**Table F-5. Post Fire Test - Corrected Leakage Test Results**

| Test       | Leakage Rate (m <sup>3</sup> /hr) |        |        |        |        |        |         |        |                           |
|------------|-----------------------------------|--------|--------|--------|--------|--------|---------|--------|---------------------------|
|            | @5 Pa                             | @10 Pa | @20 Pa | @30 Pa | @50 Pa | @70 Pa | @100 Pa | @5 Pa  | @ Highest Static Pressure |
| Bulkhead A | 69.8                              | 88.0   | 105.6  | 127.0  | 164.3  | 200.4  | 239.8   | 74.8   | 247.7                     |
| Sample 1   | 154.6                             | 163.9  | 192.9  | 216.2  | 261.5  | 300.5  | 349.4   | 160.1  | 357.8                     |
| Sample 2   | 173.5                             | 188.0  | 222.3  | 250.0  | 299.7  | 345.1  | 408.9   | 158.5  | 411.6                     |
| Sample 3   | 175.7                             | 195.2  | 229.9  | 263.0  | 314.1  | 362.3  | 419.5   | 160.5  | 421.3                     |
| Sample 4   | 104.5                             | 120.2  | 149.3  | 174.5  | 218.2  | 257.2  | 303.2   | 112.0  | 303.0                     |
| Bulkhead A | 117.3                             | 127.2  | 150.4  | 167.5  | 199.5  | 232.2  | 270.7   | 117.6  | 270.8                     |
| Bulkhead B | 31.7                              | 59.6   | 73.8   | 90.6   | 117.4  | 141.0  | 171.3   | 58.6   | 174.1                     |
| Sample 8   | 900.3                             | 958.5  | 1078.4 | 1168.2 | 1387.5 | 1534.3 |         | 891.9  | 1531.9                    |
| Sample 10  | 1018.2                            | 1104.7 | 1219.5 | 1364.7 | 1571.1 |        |         | 1063.1 | 1579.1                    |
| Bulkhead B | 66.3                              | 75.3   | 87.1   | 100.0  | 121.9  | 141.4  | 166.1   | 69.0   | 167.6                     |
| Bulkhead C | 94.3                              | 132.0  | 176.0  | 208.6  | 278.5  | 341.1  | 425.4   | 153.7  | 432.8                     |
| Sample 9   | 800.2                             | 859.7  | 976.8  | 1080.7 | 1280.6 |        |         | 826.7  | 1281.7                    |
| Sample 11  | 726.6                             | 810.5  | 980.1  | 1092.2 | 1347.9 |        |         | 764.9  | 1362.1                    |
| Bulkhead C | 206.7                             | 230.4  | 264.9  | 291.3  | 342.2  | 397.3  | 466.8   | 206.2  | 464.4                     |
| Bulkhead D | 44.9                              | 69.5   | 103.5  | 127.7  | 168.9  | 211.1  | 257.0   | 77.5   | 256.6                     |
| Sample 6   | 401.9                             | 582.2  | 782.7  | 959.7  | 1217.2 | 1504.2 |         | 586.3  | 1491.0                    |
| Sample 7   | 575.0                             | 698.5  | 929.3  | 1066.6 | 1355.4 |        |         | 661.0  | 1383.0                    |
| Bulkhead D | 101.7                             | 113.5  | 144.3  | 163.6  | 195.9  | 236.6  | 291.6   | 110.2  | 295.8                     |
| Bulkhead E | 25.2                              | 40.4   | 63.6   | 80.2   | 108.7  | 131.0  | 162.0   | 44.1   | 165.3                     |
| Sample 5   | 1091.9                            | 1195.9 | 1485.5 |        |        |        |         |        |                           |
| Bulkhead E | 74.0                              | 77.3   | 140.0  |        |        |        |         | 73.5   |                           |